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ABSTRACT

The fundamental principles underlying the application of electricity to tractors and farm equipment are presented. An understanding of the material in the basic manual will enable the service man to understand better the service procedures covered in service manuals on electrical equipment. Topics dealt with are fundamentals of electricity, storage batteries, circuits, and combination motor and generator. (NJ)

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ED112257

# The Tractor Electrical System

(VT 102 067)

# A Teaching Reference

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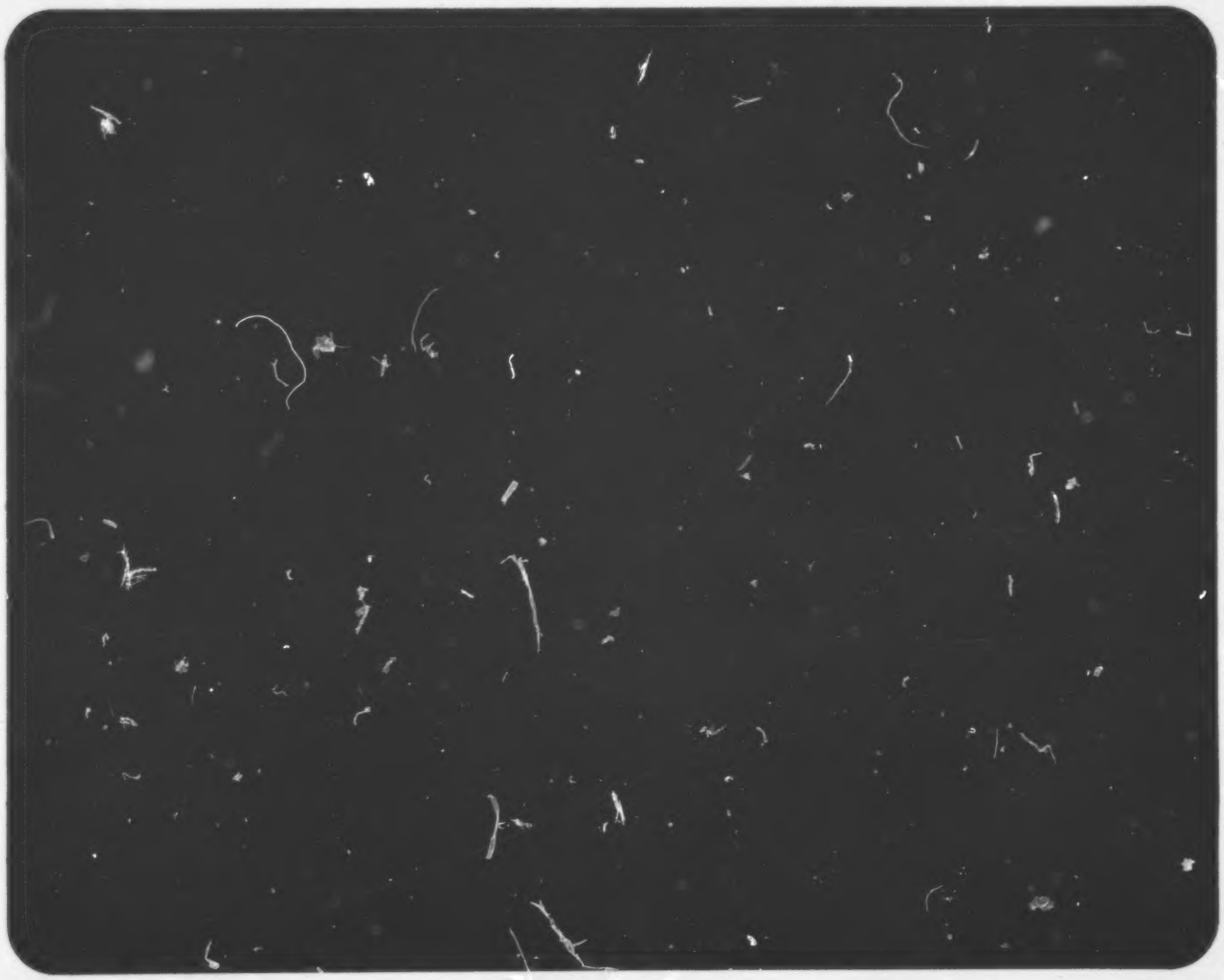

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# INTRODUCTION

Since the discovery of electricity, a great deal has been learned about it and many ways have been devised to use it in performing tasks which were formerly done by hand, or other cumbersome methods. Electricity has made possible the introduction of many labor-saving devices such as electric light, electric power for motors, and electric heating units.

Electricity, as it is used to power cranking motors for engines, makes starting of engines much easier and less hazardous than the previous hand cranking method. The modern gasoline engine could not be run without electricity to furnish the spark to ignite the fuel in the cylinder. These and many other applications of electricity are used on our modern tractors and farm equipment.

On the following pages is a discussion of the fundamental principles behind the application of electricity to tractors and farm equipment. It is the aim of this manual to present these fundamentals in a manner which will make the farm equipment service man better able to understand the operation of the electrical equipment on farm machines. An understanding of the material covered in this basic manual will enable the service man to understand better the service procedures covered in service manuals on electrical equipment.

# FUNDAMENTALS OF ELECTRICITY

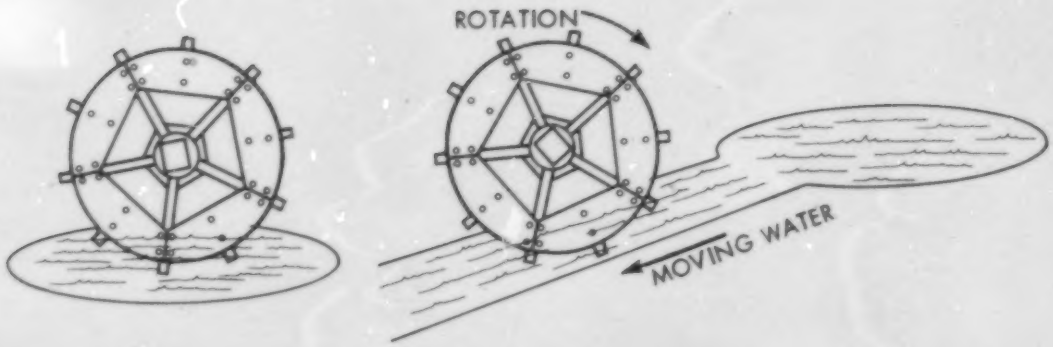
## Definition of Electricity

Electricity can be defined briefly as a form of energy. Since energy is the capacity for doing work, it follows that electricity, if properly harnessed, can perform work. This work can take the form of motion as in the case of electric motors, or heat as in electric heaters, cigarette lighters, etc. or it can produce light as in a light bulb.

## Nature of Electricity

In order to have a better understanding of how electricity can be used to perform work, we need to know something about the nature of this form of energy. No one knows specifically what electricity is. Electricity is present in everything, for example, our body, clothes, paper, furniture etc. The reason that we are not aware of its presence is because it is not in motion.

Electricity can be compared with water. For example, if we were to place a water wheel in the middle of a pond, the wheel would not turn, but if we place the wheel in a position where water can flow past the blades, the wheel would turn. (Illust. 1.) The motion of the water causes the wheel to turn. The same is true of electricity, when we put it in motion we can obtain work from it.




Illust. 1

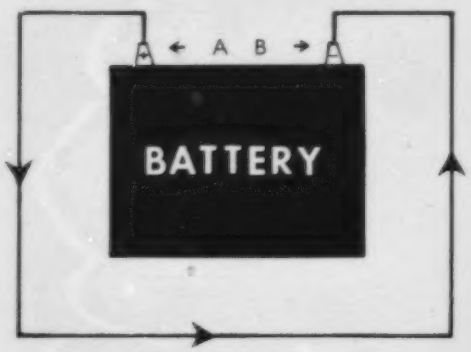
In order to get the water wheel to move, it was necessary to have a current of water flowing; and so it is with electricity. There must be a "current" or "flowing" of electricity before we can get any work out of it.

To continue our water analogy, we know that in order to move the water to perform work, it is necessary to have a trough or pipe to carry the water from the source to where it is used. So it is with electricity, it must also have a path to follow. This path is called a conductor. This conductor can be made from any material which will conduct electricity. Some of these are, copper, aluminum, steel or iron.

Electric current will flow in a conductor provided there is a pressure forcing the electricity to move. This pressure is called electromotive force or voltage. The amount of pressure or voltage which is required to make the current flow in a conductor varies depending upon the amount of resistance in the conductor. There is resistance to current flow in the conductor just as there is resistance to the flow of water in a pipe.

## ELECTRICAL CIRCUIT

Electricity can be made to flow in a conductor provided there is pressure (voltage) applied. This is true provided that the conductor is arranged to provide a continuous path from the source of electricity back to the source. This conducting path is called an electric circuit. To illustrate this, let's use a source of electricity that we are all familiar with, a storage battery. The storage battery is a chemical source of electricity. As we know, this battery has two posts or terminals, one of which is marked "positive" (+) and the other "negative" (—).




Illust. 2

If one end of a wire is attached to the positive terminal "A" and the other end to the negative terminal "B," we will have created an electric circuit and current will flow through the wire (Illust. 2). This is true because we have created a continuous path from the positive terminal of the battery through the wire and back to the battery at the negative terminal. The direction of current flow will be from positive to negative.

## RESISTANCE

Any conductor has resistance to current flow, so it is necessary to overcome this resistance with pressure (voltage) to make the current flow. With a given pressure (voltage) such as is produced by the battery, the amount of current which will flow will depend upon the amount of resistance in the circuit. The more resistance there is in the circuit, the less current will flow and conversely the less resistance in the circuit, the more current will flow. In order to perform work with electricity, it is necessary to put it in motion (that is) we must have current flowing in a sufficient amount to do the work required. Therefore, it is necessary to pay close attention to the amount of resistance present in a circuit.

### FACTORS AFFECTING RESISTANCE IN A CIRCUIT

There are a number of factors which affect the amount of resistance in a circuit and these must all be considered when setting up an electrical circuit to do a particular job.

For example, the simple circuit in Illust. 2 has only the wire conductor to cause resistance to current flow. In this case, the factors affecting the resistance are:

1. The material from which the wire is made.

   Metallic substances such as copper, aluminum, steel or iron are good conductors. This is because they have a relatively low resistance to current flow. These materials, therefore, are often used as conductors. Copper is by far the most commonly used because it has a low resistance to current flow and is relatively cheap. Copper is also desirable for conductors because it is soft and bends easily without breaking. This simplifies forming the conductor in the shape desired to make up a circuit.

   Most metallic substances have a relatively low resistance to current flow and may, therefore, be used as conductors. Engine blocks or the frame of a tractor can be used as conductors and often are used to reduce the amount of wire necessary to complete circuits.

2. Diameter of Conductor.
   Another factor which affects the amount of resistance present in the wire used in Illust. 2 is the diameter of the wire. It has been determined that the larger the wire, the less resistance to current flow will be present. Therefore, if a circuit must carry a large amount of current, a wire of large diameter should be used.

3. Length of the conductor.
   The total resistance of a circuit depends also on the length of the wire since a given amount of resistance per unit length is present. This being the case, the length of the wire becomes an important factor when considering the current carrying capacity of a circuit.

4. Temperature of the conductor.
   When the temperature of a conductor increases, the resistance also increases in direct proportion, that is, for each degree rise in temperature of the conductor, there is a corresponding increase in the amount of resistance. This fact makes it important that the conductor be of sufficient size to carry the current required without heating.

### OTHER TYPES OF CONDUCTORS

We have considered up to this point resistance as it exists in a wire conductor such as used in the simple circuit shown in Illust. 2. However, the conductor need not necessarily be a wire. It can be the frame of a machine or unit of a machine. It can also be a liquid. The liquid in a storage battery is a conductor of electricity. Even air will conduct electricity but the resistance is so high that it takes a great deal of pressure (voltage) to make the current flow.

### INSULATORS

We have considered materials with relatively low resistance which are used as conductors of electricity, but what about other materials with high resistance to current flow. Many materials have such a high resistance to current flow that no current will flow through

them unless the pressure (voltage) is very high. This makes them of little value as conductors. Many of them do have a value however, to prevent current from flowing in the wrong path. Electric current will flow through the material offering the least resistance. Therefore, it is necessary to use a material of high resistance around conductors to prevent the current from deviating from the path provided. This material is called insulation. Rubber, fabrics, glass, enamel, and air are examples of good insulators and are commonly used for that purpose. These materials have such a high resistance to current flow that a thin layer around a conductor will prevent current from straying from its normal path. Air, while it is a good insulator, is not too practical for insulating wires because it will not support the wire and keep it away from other conductors.

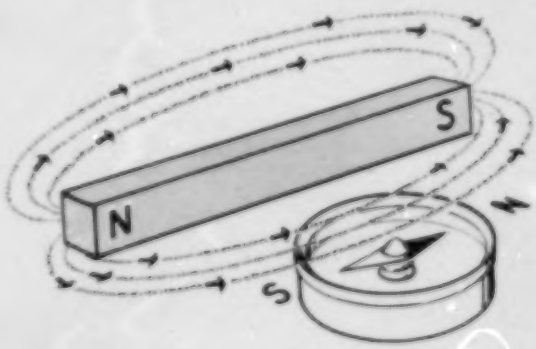
## Magnetism

Another phenomenon which is closely associated with electricity is magnetism. Like electricity, very little is known about what it actually is. There is, however, a great deal known about how it acts. In order to understand how electricity is used to do work, it is necessary to consider magnetism because it works together with electricity in many cases.

Magnetism may be defined briefly as "the power to attract." We mean by this that certain materials have the power to attract other similar materials. The force which causes this attraction is known as "magnetism." There are only a few materials which have this magnetic property, such as iron, nickel, cobalt and their alloys. All other materials which do not have this property are considered nonmagnetic.

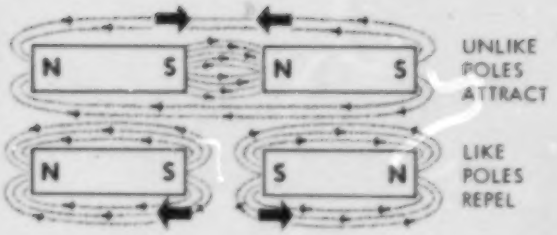
When magnetism was first discovered, it was found that a magnetized piece of elongated iron ore, in addition to having the power to attract other ferrous material, would always point toward the North if suspended in air. It was also learned that if two pieces of elongated iron ore were placed near each other that the ends which pointed to the North pole of the earth would not be attracted to each other, but would be repelled. If on the other hand, one of the pieces was reversed, then the pieces would be attracted to each other. Since one end of this material always pointed toward the North pole of the earth when suspended in air, it was termed the North pole of the material which was called a "magnet." The opposite end then, was termed the South pole. This principle became the basis for the first compass.

Further study of these so-called "natural magnets" revealed that the attraction between two of these was limited to a short distance. This indicated that there was a limited area around these magnets in which the attractive force was apparent. This then, was called a "magnetic field." It was also learned that the attracting force became stronger the closer the magnets were placed together. This indicated that around a magnet there are invisible lines of force which are close together near the magnet and progressively farther apart away from it. These invisible lines are represented graphically, as shown in Illust. 3. Since




Illust. 3

the North pole is attracted to the South pole of another magnet, it follows that the unlike poles of one magnet would be attracted to each other and the lines of force around the magnet have a direction from the North to the South pole, as shown in Illust. 3. As previously stated, unlike poles of a magnet attract each




Illust. 4

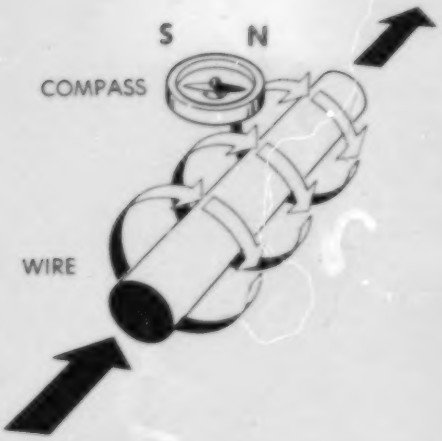
other and like poles repel when placed near each other. Illust. 4 shows the direction of the magnetic lines of force in each case. You will note that a large number of lines of force pass from the North pole to the South pole when opposite poles are placed near each other making a strong magnetic field between the poles. When the like poles are near each other, the lines of force repel each other and no lines of force are traveling between the like poles. The magnetic field between the two like poles is, therefore, very weak. These facts are the basis for the fundamental law of magnetism, which is, "Unlike poles attract and like poles repel each other."

Another property of "natural magnets" is that if a piece of iron which is not a natural magnet, such as a nail touching a natural magnet, it too becomes magnetized. When this happens, the nail will have a North and South pole just like the natural magnet. The end of the nail touching the natural magnet will have the opposite polarity to the magnet and is, therefore, attached to it. As soon as the nail is removed from the natural magnet, it loses its magnetism and cannot, therefore, be considered a natural or permanent magnet.

It has been found that soft iron becomes magnetized easily but loses its magnetism quickly when removed from a magnetic field. Hard iron, such as steel alloys are much harder to magnetize, but will retain magnetism much longer. Due to this fact, a permanent magnet may be produced out of certain hard materials by subjecting them to a strong magnetic field.

## ELECTROMAGNETIC FIELDS

With this basic knowledge of magnetism, let's return to our basic electric circuit shown



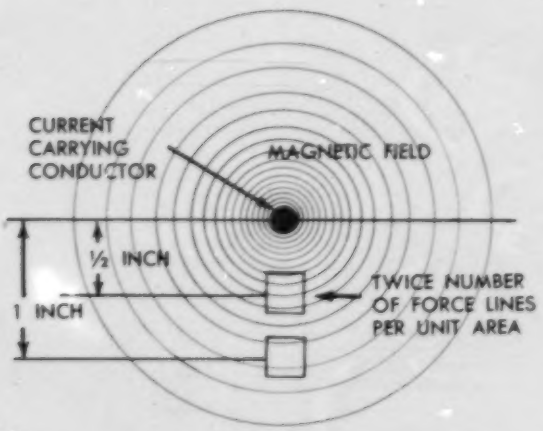

Illust. 5

in Illust. 2. Using a compass needle, we find that when the compass is placed near the wire through which current is flowing, the needle points toward the wire (Illust. 5). Since a magnetic force is the only force that will deflect a compass needle, it is apparent that a magnetic field is produced by the current flow in the wire. In the case of the straight conductor, the lines of force form concentric circles around the wire. In this respect, the field differs from that of the permanent magnet. There are no magnetic poles in the conductor at which the lines of force can enter or leave. The strength of this magnetic field is increased with an increase in the current flow. The increase in the number of lines of force is in direct proportion to the increase in current, and the field is distributed along the full length of the conductor.

As in the case of the magnetic lines of force set up by the permanent magnet, the lines of force around a wire travel in a definite direction. The direction of these lines of force is dependent upon the direction of current flow in the wire. If the direction of current flow is known, then the direction of the lines of force around the conductor can be determined by what is known as the right hand rule (Illust. 6). If the right hand grasps the conductor with the thumb pointing in the direction of current flow, the the fingers will point in the direction of the lines of force around the conductor. If the direction of current flow is not known, then a compass may be used to

Illust. 6

determine the direction of the lines of force. See Illust. 5. If the compass is placed above the wire, the North pole of the needle will point in the direction of the lines of force. With this information, the direction of current flow can be determined by the right hand rule.




Illust. 7

The extent of the magnetic field around a conductor is limited as in the case of the permanent magnet and is progressively weaker as the distance from the conductor is increased. This is shown graphically in Illust. 7 as a series of concentric lines around the conductor which are progressively farther apart as the distance from the conductor is increased. For example, with a given current traveling in a conductor, there will be twice the number of lines of force at a distance of ½ inch from the conductor as there will be at a distance of 1 inch. The number of lines per unit area is called "density." The density of the field being greatest at the conductor means that the most useful portion of the magnetic field is near the conductor.

Illust. 8

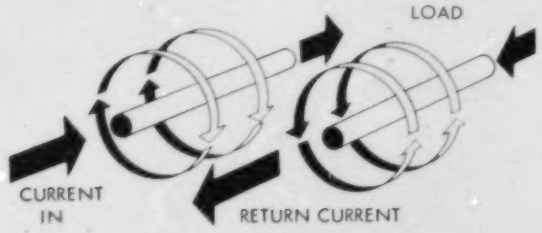
If we take a straight current carrying conductor and bend it into a loop, the lines of force are still traveling around the conductor at right angles to it, as shown in Illust. 8. The lines of force all pass through the inside of the coil. This concentrates the lines in this area and, therefore, materially strengthens the field without increasing the current flow. In addition, note that the polarity on one side of the loop is opposite to that on the other side. This can be observed by using a magnetic compass. We see, then, that the magnetic field around the loop is very similar to that produced by a permanent magnet.

## COMBINED MAGNETIC FIELDS

We now know that when current flows in a straight conductor, there is a magnetic field created around the conductor. We have also learned that the magnetic lines of force are always in a plane at right angles to the con-

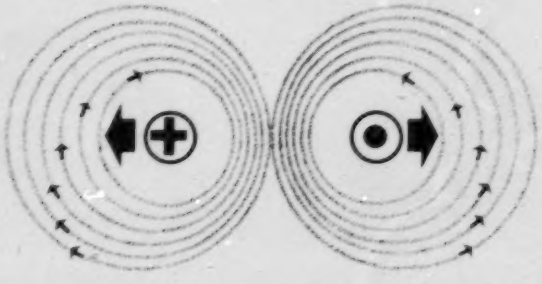
ductor and the direction of the lines depends upon the direction of current flow. Now let's consider what happens to the magnetic field around two parallel conductors which are adjacent to one another.

In order to keep track of the direction of current flow, we will mark the end of one conductor with a (+) to indicate current flowing away from that point and one end of the other with a dot (•) to indicate current flowing toward that point. See Illust. 9.




Illust. 9

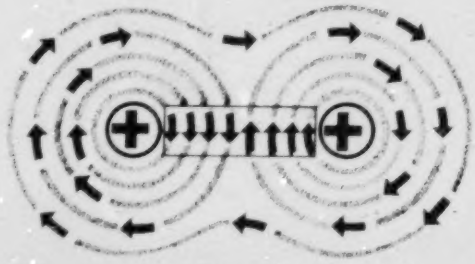
With current flowing in opposite directions, as shown in Illust. 9, the magnetic lines of force around the conductors will be in opposite directions also. You will notice, however, that the lines of force between the conductors is traveling in the same direction. We learned when considering permanent magnets that lines of force traveling in opposite directions were repelled by each other. This is also true of the magnetic lines of force around parallel conductors. This means that the lines of force around the conductors in Illust. 9 will be compressed and forced between the conductors when the conductors are placed close together. See Illust. 10.



Illust. 10

The total number of lines of force between the conductors will be the same as the total number of lines outside since all the loops are continuous. The area between the conductors is very limited, however, as compared to the area outside. This causes a condition of unbalanced density. This unbalance causes forces to act on both conductors in a direction which will increase the enclosed area and thereby minimize the unbalance. This will cause the conductors in Illust. 10 to try to move apart. This characteristic of magnetic fields around conductors to try to balance the field by forcing the conductors apart is called interaction between current carrying conductors. This principle is the basis for all electric motors.

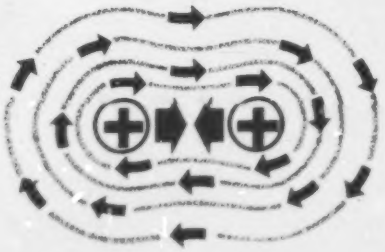
We have seen what the magnetic fields around two parallel current carrying conductors is like when the current is traveling in opposite directions, so now let's consider what happens if the current is traveling in the same direction through both conductors.



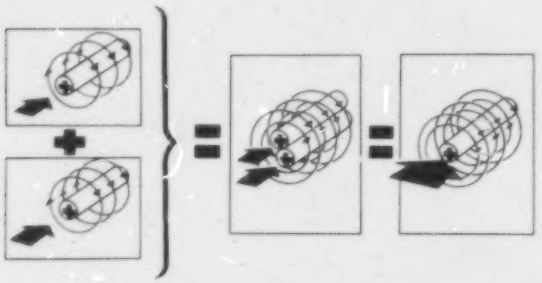
Illust. 11

If we apply the right hand rule, we see that the magnetic lines of force will be traveling in the same direction around each conductor. See Illust. 11. You will note in this case, the lines of force between the conductors are traveling in opposite directions. Since the lines of force repel each other, they can't pass between the conductors and are diverted around both conductors, as shown in Illust. 12.

This again causes an unbalanced field, but in this case, the strong field is outside the conductors and so the tendency is to force the conductors closer together to balance the field. You will notice also that the lines of force of the two conductors have joined, and

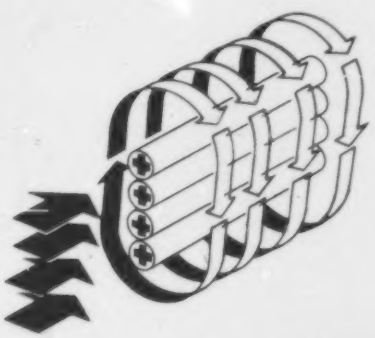


Illust. 12



Illust. 13

there are now twice the number of lines that each conductor alone produced. If the conductors are allowed to come together, the lines of force will surround both in the same manner as if there were only one conductor carrying twice the current. See Illust. 13.



Illust. 14

If we add several more conductors each carrying an equal amount of current in the same direction, the lines of force join in the same manner as when there were only two, but the number of lines of force is doubled because there are twice the number of conductors. See Illust. 14.

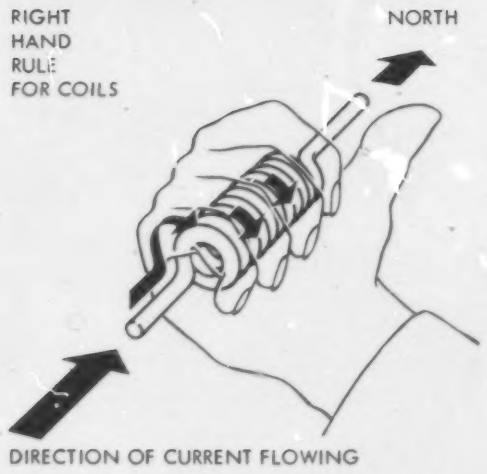
This building up of the strength of a magnetic field around conductors by increasing the number of conductors is the principle used in generator fields coils and ignition coils.

## ELECTROMAGNETS

We have seen how several adjacent conductors carrying current in the same direction will cause a strong magnetic field to be built up around them. Now, let's apply this principle to a single conductor again but with the conductor wound around a common core so that several turns are adjacent to each other. See Illust. 15.

Illust. 15

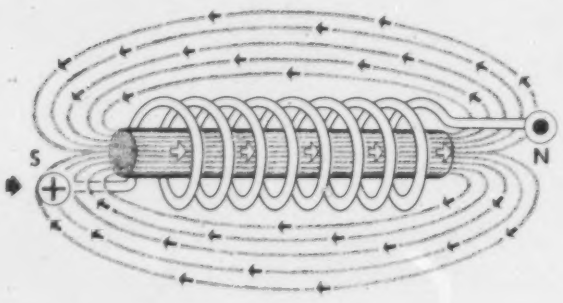
If we cause current to pass through this simple coil we see that since the current is traveling in the same direction through each loop of the coil, the magnetic lines of force are also traveling in the same direction around the wire. As we have seen before, when current is traveling in the same direction through multiple conductors, the lines of force around each conductor join and surround the several conductors. This is also what happens here. The lines of force join and travel around all of the loops of the coil, entering the coil at one end and leaving at the other and returning outside the coil, as shown in Illust. 15. Since all of the lines of force travel down the inside of the coil the area within the coil becomes a strong magnetic field. We also see that one end of the coil has become a North pole and the other a South pole just like a permanent magnet.




Illust. 16

In order to determine which end of the coil is the North pole, all that is needed is to know the direction of current flow. With this information, the Right Hand Rule for coils can be applied. Place the right hand around the coil so that the fingers are pointing in the direction the coil is wound and the current is flowing. The thumb will then be pointing toward the North pole. See Illust. 16.

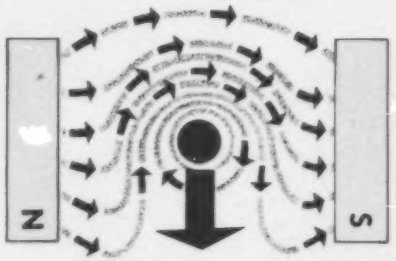
As we learned earlier, air is a rather poor conductor for lines of force so that our coil in Illust. 15 loses many of the lines of force around the coil to the surrounding air. In order to strengthen the field within the coil, it is necessary to place a soft iron core within the coil replacing the air. The soft iron can be easily magnetized and will materially strengthen the magnetic field, See Illust. 17.




Illust. 17

This then becomes a true electromagnet. With a given amount of current flowing through a coil, the strength of the electromagnet produced is directly proportional to the number of turns in the coil. The strength of the electromagnet of a given number of turns is also directly proportional to the amount of current passing through the coil. By varying the number of turns in the coil and the amount of current passing through it, virtually any strength of electromagnet desired may be obtained.

## MAGNETIC FORCE ON A CONDUCTOR



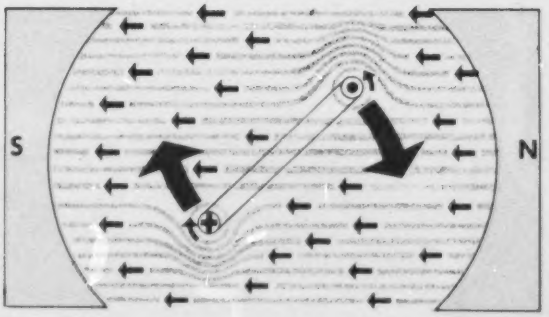

Illust. 18

We have seen how magnetic fields around single and multiple conductors act when current is passing through them. Now, let's see what happens when a current carrying conductor is placed in a magnetic field created by two permanent magnets or electromagnets placed near each other with opposite poles facing each other. As we would expect, since opposite poles attract each other, the lines of force travel from the North pole of one magnet to the South pole of the other across the air gap. Now, if we place a current carrying conductor in this magnetic field, we find that the field becomes distorted as shown in Illust. 18. This reaction between the two magnetic fields is to be expected since magnetic lines of force traveling in the same direction join and travel together, while lines traveling in opposite directions repel each other and are diverted around the conductor.

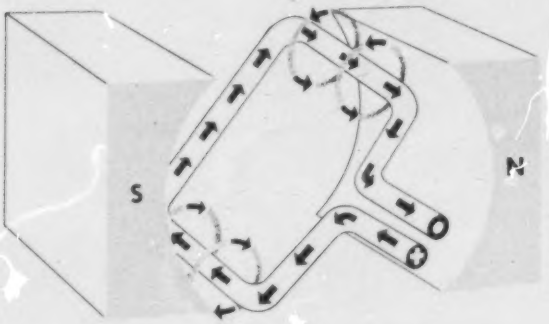


ET 14

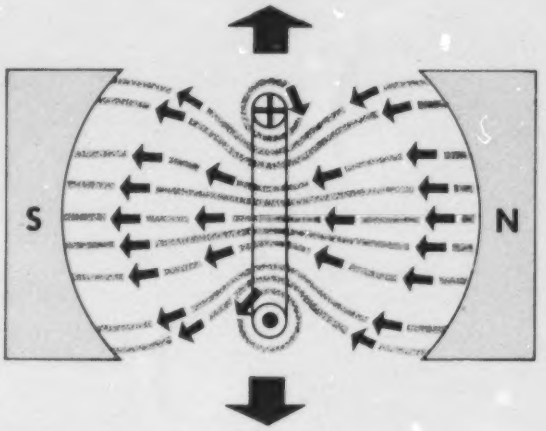
In Illust. 18 we see that the field around the conductor has lines of force traveling in a clockwise direction. The field caused by the permanent magnets has lines of force traveling from left to right. Therefore, these lines are directed around and above the conductor. This creates a strong field above the conductor and a weak field below it. Since lines of force, being somewhat like stretched rubber bands, don't like this unbalanced condition, they tend to move the conductor into the weaker field to relieve the unbalance.




Illust. 20



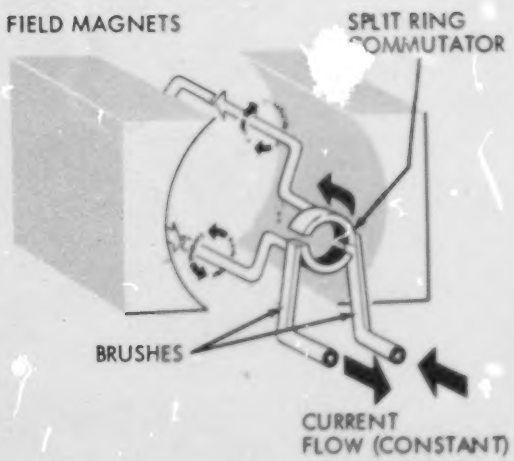

Illust. 19




Illust. 21

If the current carrying conductor, shown in Illust. 18, is formed into a loop, as shown in Illust. 19, and placed in the magnetic field, we see that the same unbalanced field condition is created See Illust. 20. The same force is then applied to move the conductor out of the field. You will notice, however, that since the current in the loop is traveling in opposite directions on each side, the field created around the conductor is also opposite. This means then that each side of the loop will be forced out of the field in opposite directions. If this loop, then, is placed on a shaft supported by bearings, it will rotate.

This force which is moving each side of the loop out of the field, Illust. 20, causes the loop to rotate until the sides of the loop are as far out of the field as possible. When this point is reached, these same forces will resist the conductors moving back into the field and the rotation of the loop will stop, see Illust. 21. This point is called the neutral position. In order to keep the loop turning, it becomes obvious that it will be necessary to change the direction of current flow through the wire loop at this point. This will reverse the magnetic field around the wire and restore the condition shown in Illust. 20. The loop will then continue to rotate. We see from this that in order to keep the loop rotating, it will be necessary to reverse the direction of current flow every half turn of the loop to keep the lines of force acting in the same direction. This can be done by means of a device called a commutator (Illust. 22). This device consists of two brushes sliding on contacts attached to each end of the wire loop. If the brushes are properly located, we see that if the current comes in at one brush and out at the other, the direction of current flow will change at the neutral point and permit continuous rotation.



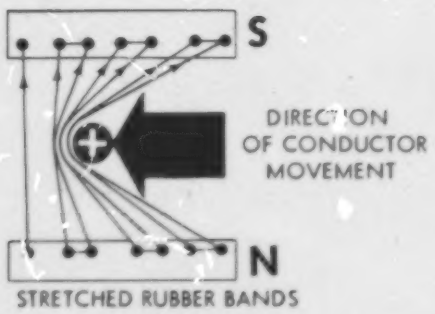

Illust. 22

This then is the principle which makes electric motors possible. As we have learned, if we increase the strength of the magnetic fields involved, the forces acting will be made stronger. Increasing the number of turns of wire around a soft iron core will create stronger field magnets (called pole shoes in an electric motor), and increasing the number of loops rotating in the field will cause a greater turning force on the conductors.

## ELECTROMAGNETIC INDUCTION

We have learned that when a current carrying conductor is placed in a magnetic field rotation of the loop results. Now, let's consider another condition which can be created with a conductor in a magnetic field.

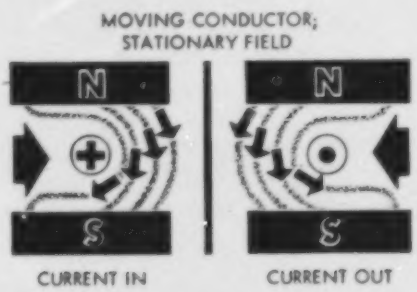
It has been found that if a conductor, which is not carrying current is passed through a magnetic field, voltage is built up in the conductor and if a complete circuit is connected, current will flow. The lines of force tend to bend around the leading edge of the conductor thus distorting the field (Illust. 23). It is this distortion of the field which causes voltage to be built up in the conductor. As we might expect, the direction the conductor passes through the magnetic field determines the direction the voltage will build up in the conductor. To determine the direction of the




Illust. 23

Illust. 24

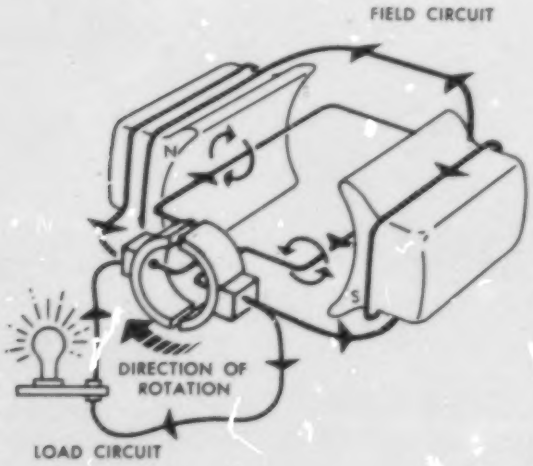
voltage induced, we can use the right hand rule again. If the fingers are wrapped around the conductor in the direction of the lines of force which are bent round it, the thumb will point in the direction of the induced voltage. See Illust. 24.




Illust. 25

Using the right hand rule in Illust. 25, we see that if the conductor is moved to the right through the magnetic field, the voltage induced will cause current to flow away from the observer, while if it is moved to the left

the voltage will build up in the opposite direction causing the current to flow toward the observer.

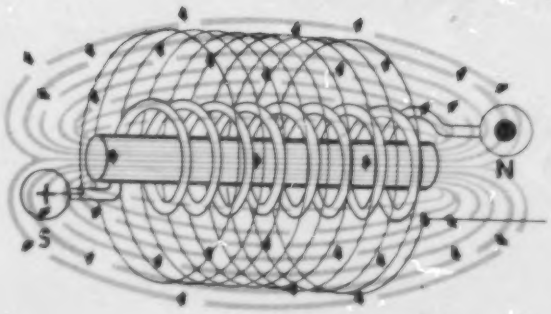



Illust. 26

If we place a wire loop and commutator in a magnetic field again as we did in Illust. 22, but instead of passing a current through the loop, we merely connect the brushes to an external circuit, such as a light bulb, (Illust. 26), then we will turn the loop so that it cuts the line of force in the magnetic field. We can see that since one half of the loop is cutting the lines in one direction and the other half is cutting them in the opposite direction, the voltage induced is in the same direction throughout the loop and a current will flow through the light bulb causing it to light. This principle is called electromagnetic induction and is used in the design of generators. We learn from this that any time a conductor distorts a magnetic field in any way, a voltage will be induced in the conductor.

As we might suspect, the rate that the conductor moves through the magnetic field has a great deal to do with the amount of voltage induced. The faster the conductor moves, the more it will disturb the magnetic field and the greater will be the voltage induced. This becomes an important factor when designing electric generators.

The principle of electromagnetic induction can be used to generate voltage in another way




Illust. 27

also, without needing a rotating coil. As we have said, voltage is produced when a magnetic field is disturbed or distorted. If we pass a current through a coil, there is a magnetic field built up around the coil. As the current starts to flow, the magnetic field starts expanding also. While this field is expanding, a voltage is being built up in the opposite direction of the voltage from the current source. This is known as counter voltage. This counter voltage causes an appreciable delay between the time the current starts to flow and when it reaches its maximum. Now, when the current is interrupted in the coil, the field starts to collapse and since the field is now changing, an induced voltage is again created in the conductor, but in the same direction as the current had been flowing which tends to keep the current flowing. This induced voltage will be higher than the original voltage according to the number of turns in the coil.

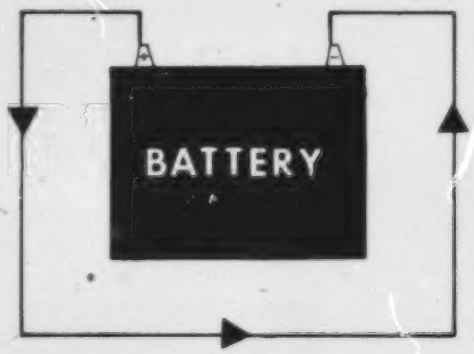
Now, if another coil is wrapped around the first coil and current is passed through the inside coil only, we find that the magnetic field is now around both coils (Illust. 27). In this case, voltage will be built up in both coils when the field expands or contracts. As a result of this condition, the voltage builds up in both coils when the current is interrupted and the field collapses. The amount of voltage built up in each coil is proportional to the number of turns in the coils. For example, if the second coil has 100 times as many turns as the inside coil, then the voltage will also be 100 times as great. This principle is used in the design of ignition coils to create high enough voltage to cause a spark to occur at the spark plug.

From the foregoing discussion, we see that electricity and magnetism are so closely related that they are inseparable. We will see as we apply these fundamentals to electrical circuits on tractors and other farm equipment that both electricity and magnetism are utilized in many ways.

## Types of Circuits

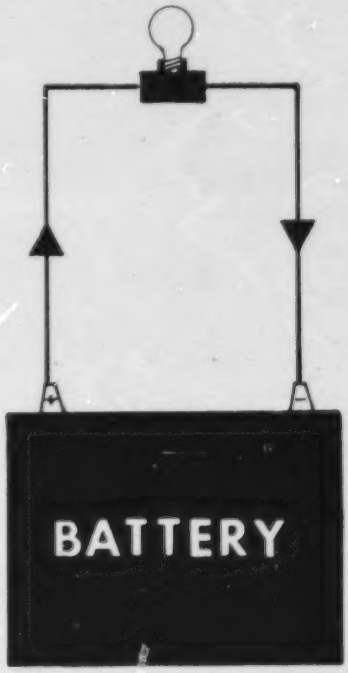
We have learned that an electrical circuit is a continuous path from the source and back to the source. We also know that this path must be composed of conductors which will permit current flow. These conductors may be copper wire, or the frame of a machine or the frame of a unit of a machine. As long as a conducting path is provided, current will flow.

As we said before, the simplest circuit is a wire connected to a source of electricity such as a battery with one end of the wire attached to the positive terminal and the other end attached to the negative terminal (Illust. 28). As we know, current will flow through the wire. The amount of current which will flow will depend upon the amount of resistance in the wire. While this is a circuit, it has no practical value since no work is being done.




Illust. 28

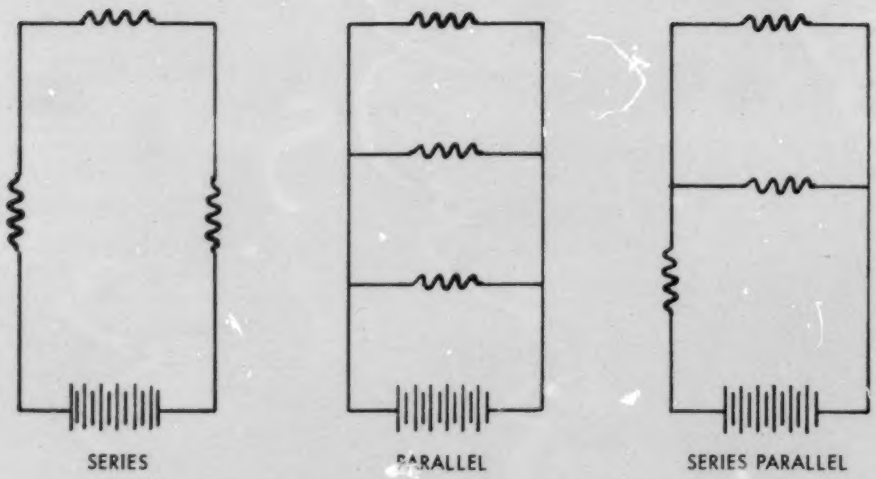
In order to use electricity for useful work, it is necessary to put into the circuit some device capable of doing some work. Suppose then that we connect a light bulb into the simple circuit, as shown in Illust. 29. As we would expect, the bulb will light. The resistance in the bulb is added to the circuit and there will be less current flowing in the circuit than before. Now there is useful work being performed since the light is burning.




Illust. 29

As circuits are made more complex due to the introduction of more devices for doing work, it becomes necessary to consider the types of circuits which can be used. There are *series* circuits, *parallel* circuits and *series parallel* circuits.

The series circuit is composed of several resistances which are connected in such a way that there is only one path in which the




Illust. 30

current can flow. A parallel circuit is one where there is more than one path for current to flow (Illust. 30). The series parallel circuit, as the name implies, is a combination of the other two wherein some of the devices are connected in series and others in parallel. These three types of circuits are important and must be understood in order to deal with electrical equipment.

## Measurement of Voltage, Current, and Resistance

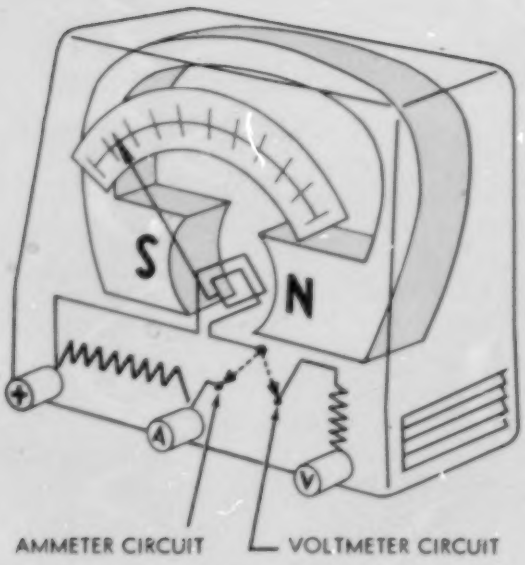
In order to properly use electricity and control it for our use, it is necessary to have some means of measuring voltage, current and resistance of the various components. We have said that electricity will flow in a conductor as a current of water flows, provided there is pressure, which we have called voltage, present to make it move. The unit of measurement for this is called the "volt." The unit of measurement of current is called the "ampere" and the unit of measurement of resistance is called the "OHM." The relationship between these three factors is very definite and conforms to a very definite rule known as "OHMS LAW." This rule states that the electrical current through a conductor equals the pressure divided by the resistance. In terms of the electrical units of measurement, this may be stated as:

$$\text{AMPERES} = \frac{\text{VOLTS}}{\text{OHMS}}$$

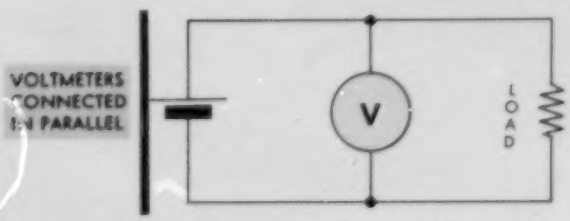
By means of this equation if two of the quantities are known, the third can be calculated. It follows then that we must have some way of measuring at least two of these factors.

In order to make these measurements, it is necessary to have instruments which will measure volts and amperes. These instruments are called voltmeters and ammeters, or a combination of both. Most modern meter movements are of the moving coil type which consists of a permanent horse shoe or hoop shaped magnet and a movable coil. Current flowing through the movable coil reacts with the permanent magnetic field causing the coil to rotate against a light spring tension. The relative movement of the coil is in proportion to the amount of current flowing in the windings. A pointer attached to the coil moves across a calibrated scale indicating the amount of current flowing in the coil. See Illust. 31.

The same meter movement can be used for either a voltmeter or an ammeter. It becomes a voltmeter when connected in parallel with the circuit, and an ammeter when connected




Illust. 31

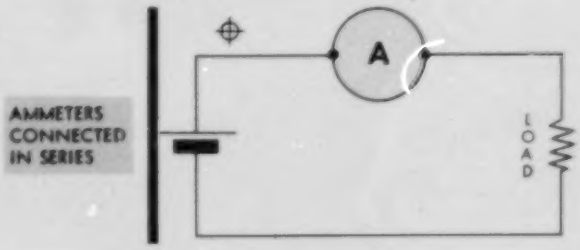



Illust. 32

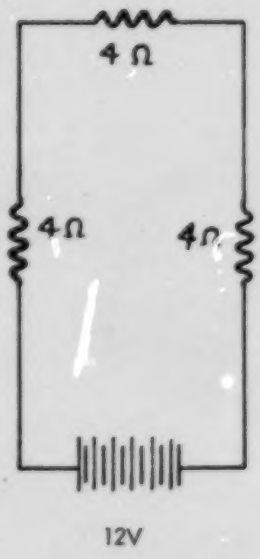
in series with the circuit. In order to obtain accurate readings with these instruments, it is important that they do not disturb the circuit when they are connected into it.

A voltmeter for example, being connected in parallel with the circuit (Illust. 32) must be a high resistance unit so that very little current can flow through the meter. The ammeter on the other hand must be a very low resistance unit because it is connected in series with the circuit (Illust. 33) and must not disturb the circuit when connected.

Some meters are equipped to measure either volts or amperes depending upon how they are connected. With this type of meter, you will notice that when used as an ammeter, there is a conductor connected in parallel with the meter movement( called a shunt) which carries most of the current, and only a small amount passes through the meter. When it is connected as a voltmeter, a high resistance is in series with the meter to allow only a very small amount of current to flow through the meter.




Illust. 33




Illust. 34

In order to measure the resistance in a circuit, it is necessary to use a third type of meter called an OHM meter. We said before, however, that if we could measure two of the unknowns in OHM's law, we could calculate the third. So, for our purposes, we will consider measuring voltage and current and calculate the resistance where necessary.

We can measure voltage by connecting a voltmeter across the circuit. This then, measures the pressure or potential difference between the two points. For example, if a volt-

meter is connected across a 12 volt battery, there will be a reading of 12 volts; however, if the meter is connected across one cell of the battery, there will be a reading of 2 volts. Because the cells are connected in series, the voltage is multiplied. In the same manner, voltage measurements may be taken in a portion of a circuit connected to a battery. For example, if a voltmeter is connected across any one of the resistances in the circuit shown in Illust. 34, a voltage reading can be taken. This will be the potential difference between one side and the other of the resistance. The sum of the readings across each resistor in the series circuit, shown in Illust. 34, will equal the voltage reading across the battery terminals. The readings across individual segments of a circuit are called "Voltage Drop" and the total voltage drop is equal to the potential at the source. Measuring voltage drop in a segment of a circuit is a common way of detecting a poor connection in a circuit since a connection which is poor, will have a high resistance to current flow and, therefore, a large voltage drop.

In a parallel circuit, the voltage drop across each resistor will be equal to the potential of the current source since there is a separate path for current to flow through each resistor.

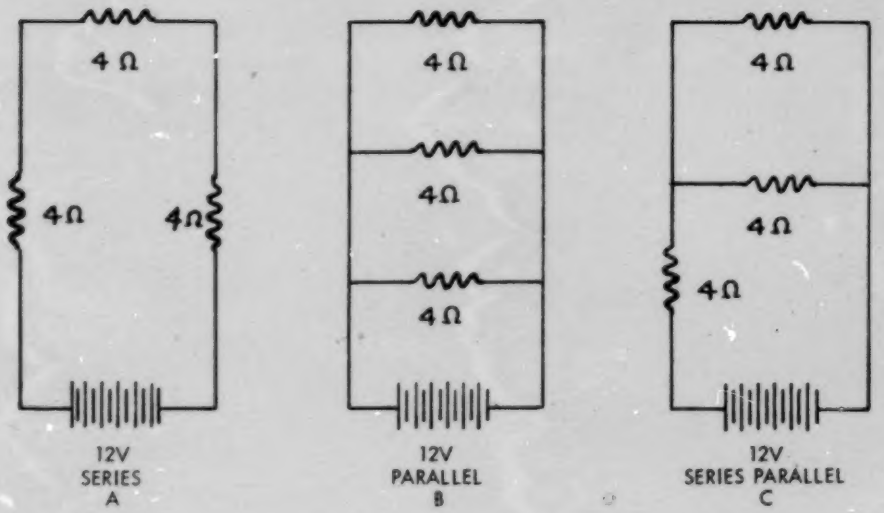
## Measurement of Electric Power

We have said that electricity is a form of energy and that if properly harnessed can be made to do work. In order to be able to determine the amount of work that electricity is doing, we need a unit of measurement which will indicate this. The amount of work which is being done is normally considered in terms of rate of work per unit of time. The term used to describe this is power. Power then, is the rate of doing work. The unit of power commonly used is the horsepower. One horsepower is equal to 33,000 ft. lbs. of work per minute.

When dealing with electricity, the unit of measurement of power is the "Watt." In terms of horsepower, the watt is equal to 1/746 of a horsepower.

The power that is being used in a circuit can be readily determined by measuring the voltage and current in the circuit and multiplying them together. In other words, Power (Watts) = VOLTS X AMPERES. If we substitute values in this equation, we see that 1 watt equals the amount of power produced when one ampere is flowing under one volt pressure. We can see from this equation that as the power required increases with the same voltage present, the current will increase. This is a very basic formula which explains why the current draw in a circuit varies with the load imposed.

# Current Flow in Series and Parallel Circuits




Illust. 35

We have learned from OHM's law that there is a definite relationship between voltage, current and resistance in an electrical circuit. Let's see now how this applies to series and parallel circuits with a given resistance. To illustrate this, let's connect 3 four ohm resistors in series, as shown in "A," Illust. 35. Since there is only one path for the current to flow, the total resistance in the circuit is 12 ohms. Since current $= \frac{\text{Volts}}{\text{Ohms}}$ (Ohm's Law), we find that one ampere of current will flow.

Now we will connect the same three resistors in parallel, as shown in "B," Illust. 35.

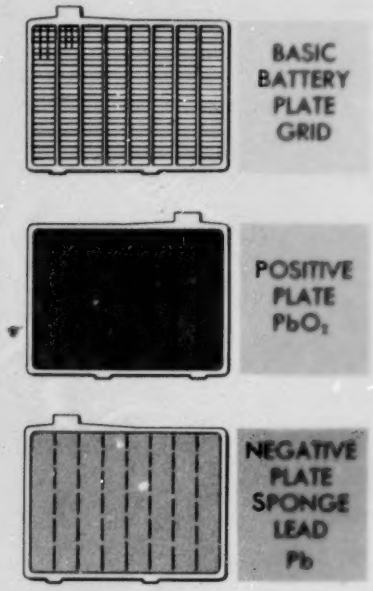
In this case, we have provided three different paths through which current can flow and there is 12 volts pressure on each. This means that each resistor will draw 3 amperes or a total of 9 amperes for the circuit.

If we take the same three resistors and make a series-parallel connection, as shown in "C," Illust. 35, we see that the total resistance will be 4 ohms plus half of the resistance value of one of the resistances connected in parallel or 2 ohms which equals 6 ohms. In this case, the current flow will be 2 amperes.

It becomes apparent then, that if a high resistance is required in the circuit, a series connection should be used and when a low resistance is desired, a parallel connection is necessary. These facts are of great importance in electrical design and must be understood before electrical circuits can be serviced.

# STORAGE BATTERIES

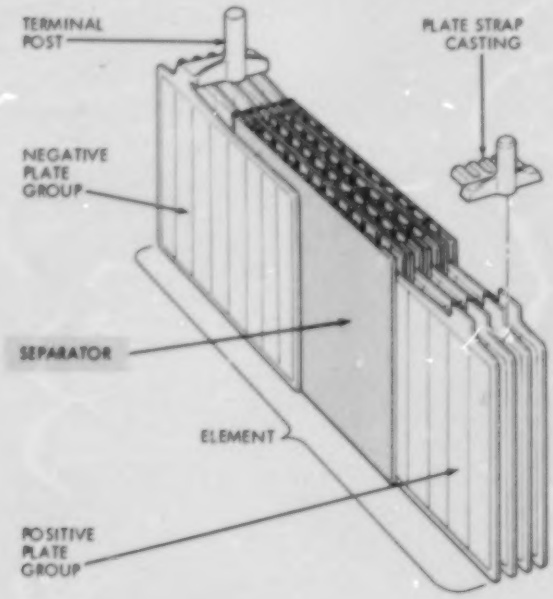
We are familiar with the fact that a battery is a source of electricity and is commonly used in electrical systems on farm tractors and farm equipment. We think of a battery as being a storage tank of electricity. This is not quite true however, because what is actually stored is chemical energy. The battery is, therefore, a device for converting chemical energy into electrical energy. Active materials within the battery react chemically to produce a flow of direct current whenever a load such as lights, cranking motor, or other current consuming device is attached at the battery terminal posts.




Illust. 36

## INTERNAL CONSTRUCTION

The internal construction on the lead-acid storage battery is relatively simple. The basic units are the positive and negative plates which are suspended in an electrolyte. The charged positive plates contain an active ingredient called "lead peroxide" ($PBO_2$) and is a chocolate brown color. The negative plates are sponge lead (PB) and are grey in color. (Illust. 35). Alternate positive and negative plates are assembled in a battery case with separators in between to prevent plates contacting each other.




Illust. 37

The positive plates are all connected together and to the positive terminal post. The negative plates are also connected together and are connected to the negative terminal post. When these groups of positive and negative charged plates are assembled into a unit with separators in between, as in Illust. 37, and electrolyte is added, they become one cell of a battery. Three such cells are connected in series to produce a 6 volt battery since each cell generates about 2 volts. A 12 volt battery is composed of 6 such cells connected in series.

## CHEMICAL ACTION

The electrolyte used in the battery cell is a solution of sulfuric acid ($H_2SO_4$) and water ($H_2O$). This solution is composed of 64% water with a specific gravity of 1.000 and 36%

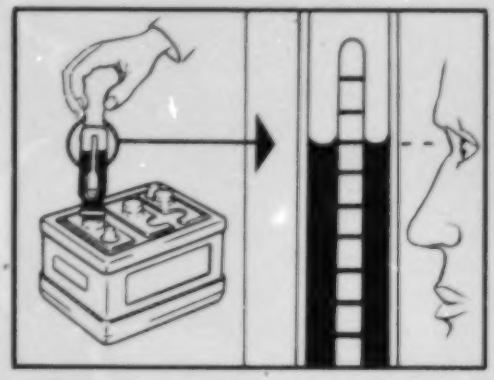
acid with a specific gravity of 1.835. The specific gravity of the resulting electrolyte is 1.270.

When the electrolyte is added to the battery cell, a chemical action takes place between the plates and the electrolyte, which causes an electrical pressure (voltage) to build up between the terminals. The voltage is normally about 2 volts per cell. When a circuit is attached to a battery, a current will flow. This is reasonable since we know that electricity is present in virtually all materials and only requires a pressure to get it moving.

The chemical action which takes place in a battery during discharge is a changing from one compound to another. For example, the lead peroxide ($PBO_2$) in the positive plate breaks down into lead (PB) and oxygen ($O_2$) and unites with the electrolyte ($H_2SO_4$) wherein the lead (PB) unites with the sulphate ($SO_4$) portion of the sulfuric acid ($H_2SO_4$) and forms lead sulphate ($PBSO_4$). The oxygen unites with the hydrogen ($H_2$) thus released forming water ($H_2O$). At the same time, the sponge lead in the negative plate unites with the sulphate ($SO_4$) to form lead sulphate on the negative plates also. As the discharging progresses, lead sulphate crystals form on both the positive and negative plates and the water goes into the electrolyte. Since the positive and negative plates become more and more alike chemically during the discharge, the potential of the battery drops and the current will finally stop flowing. The battery is then discharged. Since the sulfuric acid in the electrolyte was being used up and water was forming during discharge, the specific gravity of the electrolyte is reduced also. This explains why a discharged battery is subject to freezing during cold weather.

Due to the nature of the active materials used in a lead acid battery, it is possible to recharge the battery by applying an electric current flowing in the opposite direction from that produced during discharge. This reverse current causes the chemical action in the battery to reverse itself, that is, the lead sulphate in the plates and the water break down again and reform into lead peroxide ($PBO_2$) at the positive plates and sponge lead (PB) at the negative plates. The hydrogen ($H_2$) combines with the sulphate ($SO_4$) and forms sulfuric acid ($H_2SO_4$) in the electrolyte.

We can see from this chemical action that during discharge the electrolyte becomes more dilute since the sulfuric acid is being used up and water is forming. Conversely when the battery is charged, sulfuric acid is formed and water is used up. This causes the specific gravity of the electrolyte to go down during discharge and rise during charge. For this reason, it is possible to get an indication of the state of charge of the battery by taking a reading of the specific gravity of the electrolyte. The specific gravity of the electrolyte can be measured by the use of a battery hydrometer.

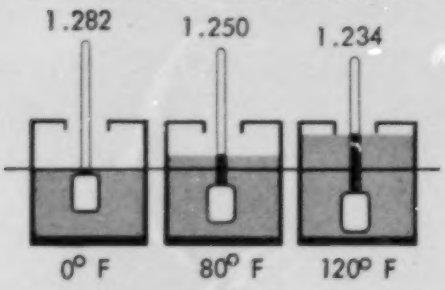


Illust. 38

This device is composed of a tube in which is placed a float which has a graduated scale on it. Some of the electrolyte is drawn into the tube and the level that the float rides at will permit a reading to be taken at the point on the scale which is even with the top of the liquid. (Illust. 38). The top of the liquid column should be held at eye level so that an accurate reading can be taken.

The specific gravity of the electrolyte is affected not only by the state of charge of the battery, but also by the temperature of the electrolyte. As the temperature of the electrolyte rises, the specific gravity is reduced. (Illust. 39). For example, if the electrolyte measures a specific gravity of 1.282 at 0°F and then the temperature is raised to 80°F, the specific gravity will have dropped to 1.250 and at 120°F, the gravity reading will be

COMPENSATION FOR SPECIFIC GRAVITY VARIATIONS CAUSED BY TEMPERATURE CHANGES




Illust. 39

1.234. This change in specific gravity at a given state of charge of the battery is due to the expansion and contraction of the electrolyte due to temperature changes. In order to get an accurate reading of the specific gravity, it is therefore, necessary to take into account the temperature of the electrolyte.

The accepted standard for measuring specific gravity is to correct to 80°F the temperature of the electrolyte. It has been found that the specific gravity of the electrolyte changes due to temperature at the rate of .004 points per 10° change in temperature. For example,

BATTERY WATER ANALYSIS

| MATERIAL | | PERMISSIBLE PARTS PER MILLION |
|---|---|---|
| TOTAL SOLIDS | | 500.0 |
| $CaCO_3$ | CALCIUM CARBONATE | 200.0 |
| $MgCO_3$ | MAGNESIUM CARBONATE | 200.0 |
| Fe | IRON | 5.0 |
| $NH_4$ | AMMONIA | 5.0 |
| $NO_3$ | NITRATES | 10.0 |
| $NO_2$ | NITRITES | 5.0 |
| Cl | CHLORIDES | 75.0 |
| Mn | MANGANESE | 0.6 |
| ORGANIC OR VOLATILE | | 50.0 |

Illust. 40

if the hydrometer reading is 1.234 and the temperature of the electrolyte is 120°F. a correction of .016 points must be added because the temperature is 40°F. above the standard of 80°F. This makes a correct reading of 1.250. If the temperature of the electrolyte is below 80°F., it will be necessary to subtract from the hydrometer reading at the rate of .004 points per 10°F. temperature difference.

As we have seen, when a battery is being discharged or charged, hydrogen ($H_2$) and oxygen ($O_2$) is being released. Since these are both gasses, they tend to form bubbles in the electrolyte and part of them escape from the electrolyte as a gas. For this reason, there is a gradual loss of electrolyte. Since these gasses which escaped have united to form water, we see that if water is added to the electrolyte, the specific gravity will be restored to the proper level as well as the level of the electrolyte with respect to plates. It is therefore, necessary to check the level of the electrolyte in a battery and replace water as necessary to prevent the level from dropping below the top of the plates. If the electrolyte is allowed to remain low, the active plates are exposed and become dry and hard. The higher specific gravity which results is also hard on the separators. Thus, if the water level is not maintained, premature failure of the battery is certain. Since water is lost more rapidly during high temperature operation than at low temperatures, the electrolyte level should be checked more frequently during the summer months.

Since water plays such an important part in the function of a storage battery, it is important that as nearly pure water as possible be used. Distilled water is the best because water with impurities in it is detrimental to the performance and life of the battery. A small amount of impure water added to a battery does not ruin it immediately, but continued use of such water will concentrate the impurities since only pure water leaves the electrolyte when gassing occurs. These impurities which may collect on the plates will shorten the life of the battery. In the table (Illust. 40) are listed the permissible quantities of materials commonly found in water which are acceptable in water for batteries.

You will see from the chart that minerals in water are particularly injurious to batteries and if present in more than extremely small quantities will be very harmful.

Water containing a high percentage of iron will permit the iron particles to travel between the positive and negative plates causing the plates to discharge.

Water obtained from volcanic areas usually contains a small amount of manganese which will combine with sulfuric acid to form a strong oxidizing agent which perforates the separators. Manganese in the amount of a few parts per million is enough to destroy a battery in six weeks time.

Water for battery use should be stored in glass, rubber, or other non-metallic containers in order to keep the water as pure as possible. Water stored in a metal container will in time pick up enough minerals from the container to make it unsuitable for battery use.

## EFFECT OF TEMPERATURE ON BATTERY VOLTAGE

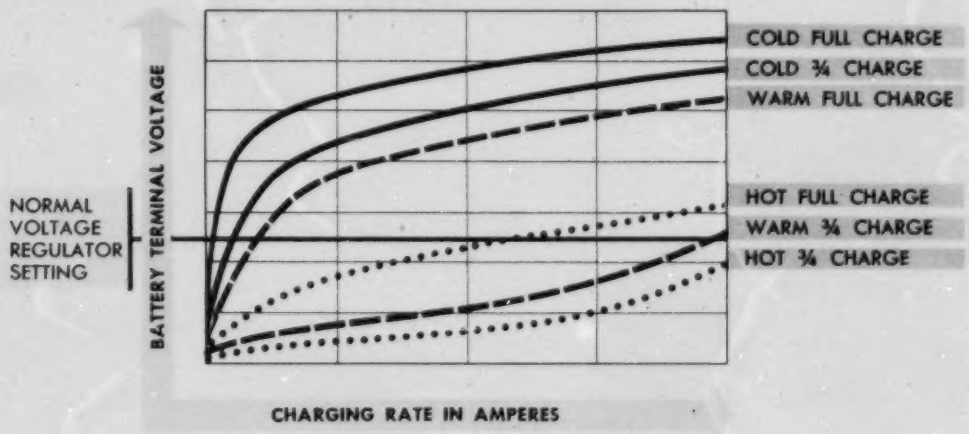
The voltage produced by a fully charged storage battery is normally a little more than two volts per cell, but this is affected by the temperature of the battery. When the temperature of the electrolyte is cold, the resistance in the battery increases.

This means that a cold battery will require a higher voltage in the charging circuit to overcome this resistance than if it is warm. Illust. 41 shows a comparison of the battery terminal voltage at various rates of charge when the electrolyte is "cold," "warm," or "hot." Voltage regulators incorporate in their design a provision for increasing charging voltage during cold weather to overcome the higher resistance under these conditions.

## BATTERIES IN STORAGE

When a lead acid battery is not being used, care should be taken to maintain the battery in good condition until it is again placed in operation. When a fully charged battery is placed in storage, it will gradually lose some of its charge because all of the chemical activity does not stop. While this discharge rate is considerably slower than when a discharge current is flowing, it still does slowly become discharged. This means that the battery should be recharged periodically to keep it in a fully charged condition.

If a battery is allowed to remain in a discharged condition over a period of time, the sulphate crystals which form on the plates become hard and will not easily break down during the charging process. This condition is commonly called a sulphated battery. Batteries which have been allowed to self-discharge over a long period of time without boosting, or which have been discharged and allowed to remain undercharged for a long period of time show an increase in internal resistance due to the hard sulphate crystals which form on the plates. Such a battery will seldom perform satisfactorily when placed in service.




Illust. 41

## BATTERY CHARGING RATE

We have learned that when a battery is discharged, the voltage at the terminals is reduced due to the fact that the active material in the positive and negative plates has become more alike chemically. This means that when the battery is being recharged, it will accept a high rate of charge at a given voltage to begin with, but as the battery becomes recharged, the voltage of the battery increases and it will accept only a small current. This is a desirable situation in that if high charging rates are used on a battery which is almost fully charged, excessive gassing takes place and the battery heats up. High charging rates when a battery is in a discharged condition are desirable for rapid recovery, but should be cut down as the battery nears full charge to prevent damage to the battery.

A battery which has become self-discharged slowly should be recharged slowly to give more time for the sulphate crystals on the plates to break down. This will happen if the sulphated condition has not existed too long. A sulphated battery will tend to operate at abnormally high voltages and if placed in an electrical system with normal regulator settings will soon become discharged. Even the maximum allowable setting of the voltage regulator can be ineffectual with such batteries because they tend to heat excessively when charged at higher rates. If such a battery is slowly recharged on a slow charger until there is no further increase in specific gravity for three successive readings taken at hourly intervals, the normal charging characteristics of the battery can often be restored.

## BATTERY CHECKS

Whenever electrical trouble is encountered, one of the first considerations should be the battery. A visual inspection of the battery can often indicate whether or not the trouble is at the battery. Mechanical damage to the battery case, leakage or heavy corrosion at the terminals are indications of battery trouble. However, any analysis of electrical or chemical conditions within the battery requires the use of reliable testing instruments.

The basic instruments required for battery testing are the hydrometer, thermometer and voltmeter. In recent years, the open circuit voltage tester has been introduced as a substitute for the hydrometer. This tester, which is essentially a voltmeter with an expanded scale, is especially convenient for checking batteries in storage since the vent caps need not be removed. It will give satisfactory results if the instructions of the manufacturer are observed carefully. For best results, however, use the battery hydrometer and correct for temperature.

Another check which can be made on a battery is the load test or high rate discharge test. The load test indicates the battery's cranking ability as well as indicating forms of deterioration and internal damage not otherwise detectable. The standard conditions for conducting load tests are as follows:

1. Battery specific gravity should be not less than 1.215 at 80°F.
2. Battery temperature should be between 70°F and 90°F.
3. Battery discharge rate should be twice the ampere hour rating of 6 volt batteries and three times the ampere hour rating of 12 volt batteries.

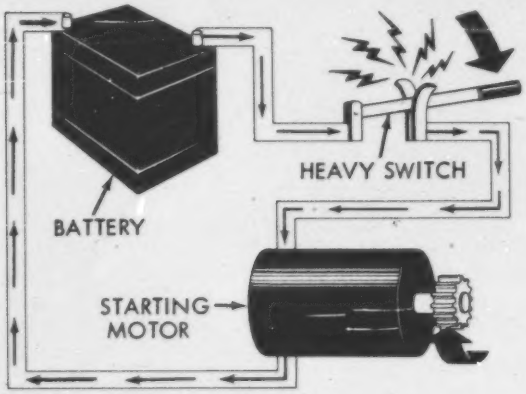
Place the recommended load across the battery for approximately 15 seconds, then measure the terminal voltage of the battery. If the terminal voltage falls below 4.5 volts on a 6 volt battery or 9.0 volts on a 12 volt battery, possible trouble is indicated.

Frequently electrical trouble existing at the battery is caused by poor connections at the battery terminals. These connections tend to corrode in time resulting in a high resistance at this point. Such a condition may cause the cranking motor to fail to operate properly. It is well to keep battery cable connections clean and tight to insure against trouble at this point. A thin coating of a heavy bodied mineral grease or oil will help to retard corrosion.

Keeping the top of the battery clean is important especially with 12 volt batteries. Wash off the top of the battery with a solution of baking soda or household ammonia and water to neutralize the acid and rinse with clear water.

# CRANKING MOTOR CIRCUIT

The cranking motor circuit consists of a low resistance cable connection from the storage battery, through a control switch, to a direct current cranking motor and returning to the battery through the engine crankcase and/or frame of the vehicle. A simplified diagram of such a circuit is shown in Illust. 42. The large amount of current used to operate the motor while cranking the engine requires that the cables be large enough and that all connections be clean and tight to carry the current without undo resistance or voltage drop. It should be noted that, since volts X amperes = watts, a six volt system uses twice as many amperes as a twelve volt system to accomplish the same amount of work. Therefore, larger conductors are required on the six volt system. It also should be noted that a twelve volt system will provide twice the number of watts (power) as a six volt system using the same amount of current (amperes).

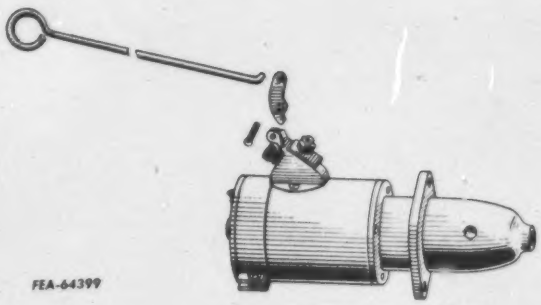



Illust. 42—Cranking motor circuit.

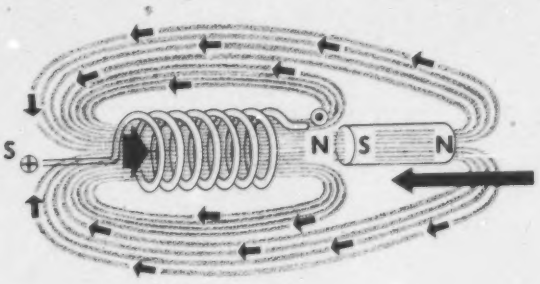
## CONTROL SWITCHES

The control switch of a cranking circuit may be any one of a number of commonly used types. It is always a low resistance, high capacity unit but may be either manually or electrically operated.

The manually operated switch may be mounted where it is directly accessible to the operator or it may be mounted on the cranking motor frame and made accessible as shown in Illust. 43.




Illust. 43—Cranking motor with manually operated starting switch.




Illust. 44.

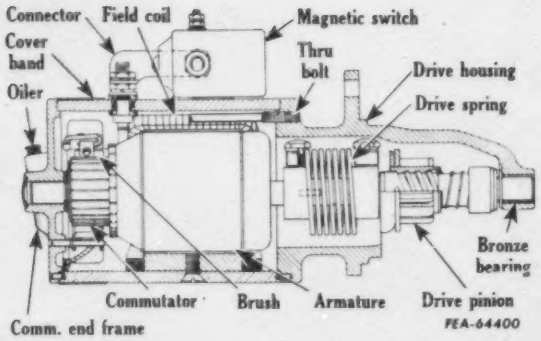
To understand the operation of the magnetic and solenoid switches we should review the basic fundamentals of the electro-magnet. We have seen how a magnetic field is strengthened by placing a soft iron core within a coil and how the polarity of the magnetic field in the core is the same as that of the coil. If the core is free to move and is placed at one end of the coil, as shown in Illust. 44, the polarity of the core will be the same as that of the coil. Because the adjacent poles are of opposite polarity the core will be drawn into the center of the coil when current flows. When current is stopped the magnetic field collapses and the core is free to move again.

The electrically operated switch is also mounted on the cranking motor frame. It is operated by a magnetic coil which is energized through a "start" contact in the ignition switch as shown in Illust. 45.

The magnetic switch consists of a high resistance winding of many turns of small wire wound around a hollow core. Floating in this core is a plunger, one end of which acts as a



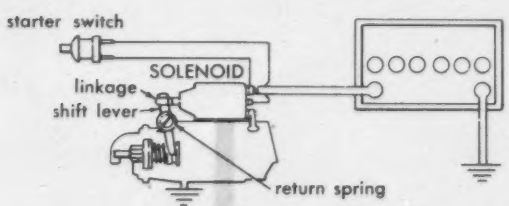
28




Illust. 45—Sectional view of cranking motor with magnetic switch.

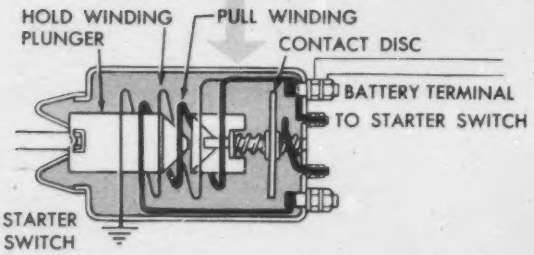
contact between the two main switch terminals which are connected in series with the cranking motor. Normally a small coil spring holds the plunger away from the main terminal contacts. When the circuit to the coil is closed through the control circuit, a strong magnetic field is created in the core, and the plunger is forced against the spring tension to make a connection between the terminal contacts. This connection completes the main circuit to the cranking motor, causing the engine to be cranked. When the control circuit is opened at the ignition key or push button switch, the magnetic field collapses and the spring forces the plunger to its original position and the cranking motor circuit is opened.

It should be noted that a standard Bendix type of drive (Illust. 45), which automatically engages and disengages the cranking motor pinion with the flywheel ring gear is used with both the manual and magnetic switches.



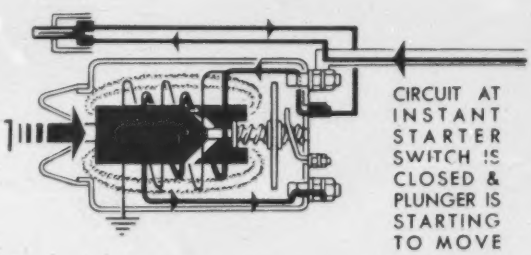

Illust. 46

Another type of control now in common use, especially on the larger engines, is the solenoid switch, which is a combination of the magnetic switch and a mechanical linkage which shifts the cranking motor pinion




Illust. 47

into mesh with the flywheel ring gear. See Illust. 46. The solenoid consists of two coils or windings, wound in the same direction, one, which is of heavy wire (known as the "pull-in" winding) connected to the motor terminal of the switch and through the motor to ground, and one, which is of an equal number of turns of fine wire (known as the hold-in winding) connected to ground (Illust. 47). The solenoid coils are energized direct from the battery through a "start" position on the ignition switch or a push button switch.



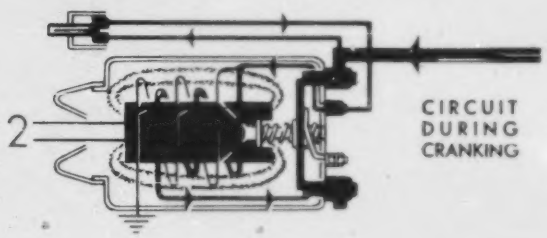

Illust. 48

Since these coils are wound in the same direction, and the current flows in the same direction, a strong magnetic field is created which pulls the plunger into the field. This movement of the plunger causes the motor pinion to engage the flywheel ring gear and at the same time closes the circuit across the two main terminals to the cranking motor. See Illust. 48.

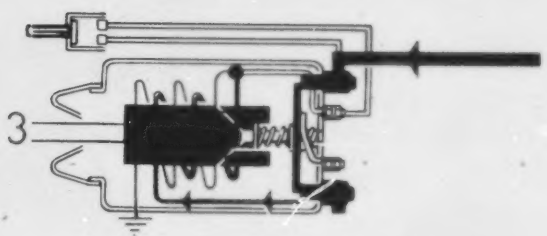
As shown in Illust. 49, the closing of the main contacts shorts out the heavy or "pull-in" winding leaving only the fine or "hold-in" winding energized during the cranking period. The initial flow of current through the heavy

or pull-in winding is of very short duration and cannot be measured with an ammeter. The flow of current through the fine or "hold-in" winding continues as long as the control circuit is closed.

It should be noted that, during the cranking period, a circuit to the ignition coil is completed. This circuit shorts out the resistance unit in the permanent ignition circuit and thus provides a "hotter" spark during the cranking period.




Illust. 49




Illust. 50

When the control circuit is opened the two windings become connected in series and are energized from the motor terminal as shown in Illust. 50. The current now flows in a reverse direction in the heavy winding, but continues in the same direction as before through the fine winding, as the same end of the fine winding is grounded. Since the number of turns in the two windings are equal, and the ampere flow is equal, but the direction of flow is opposite, the magnetic field of one coil nullifies that of the other and the plunger is returned to its original position by the spring. This movement opens the cranking motor circuit and the circuit to the ignition coil. At the same time the cranking motor pinion is pulled out of mesh with the flywheel ring gear and returns to its original position.

## THE CRANKING MOTOR

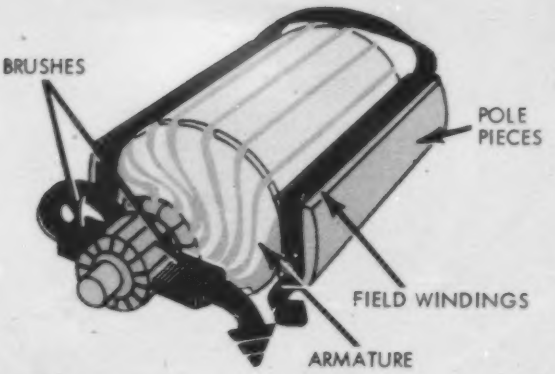
Basically, the cranking motor is known as a series wound, direct current motor designed to provide high power for a limited time from a low voltage source, such as a storage battery. It consists mainly of two, four or six field poles with windings, a wound armature with commutator and two, four or six brushes.

We have learned that a current carrying conductor, formed into a loop and mounted on a shaft, will cause the shaft to rotate when placed in a magnetic field. We have further learned that, if the direction of current flow in the loop is reversed through a commutator as the loop passes the neutral position, the loop and shaft will continue to rotate. It is obvious, then, that many loops of conductors connected in series through an equal number of segments of a commutator (as in an armature) will increase the turning ability or power in direct relation to the number of loops. It also follows that the strength of the magnetic field will effect the turning ability of the armature, and will be in direct relation to the number of field poles and to the number of ampere-turns on each pole.

The design of a cranking motor then, will depend on the power required to crank the engine on which it will be used. In all cases the armature windings are in series, through

Illust. 51

the brushes, with the field windings. The field windings may consist of two windings on four poles, four windings on four poles or six windings on six poles (Illust. 51). Note that in each case the field windings are wound to provide alternate North and South poles. Note also that in the four coil units, half the current passes through each pair of coils, and in

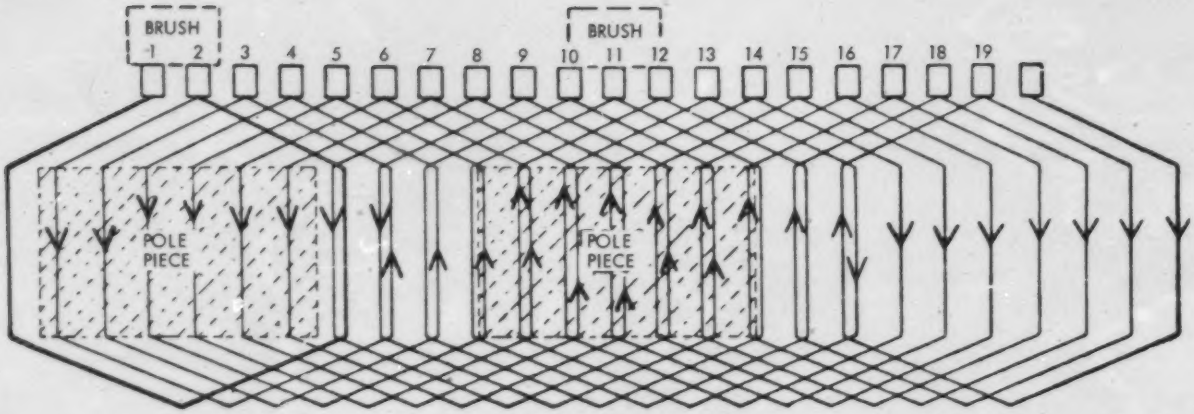



Illust. 52

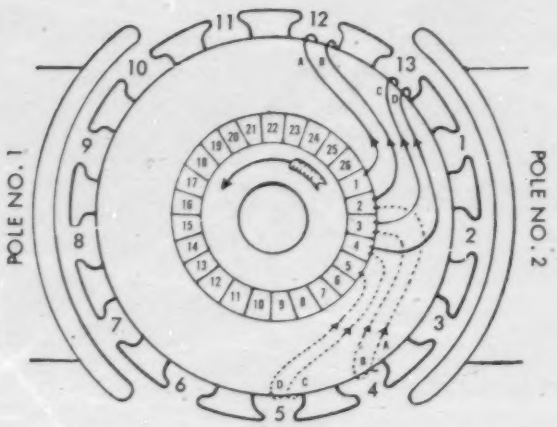
the six coil units, one third the current passes through each pair of coils.

The armature must be wound to conform to the magnetic fields provided by the field poles. In a simple two coil, two pole brush unit as shown in Illust. 52, each armature loop or winding is connected to one segment of the commutator, passes through a slot in the laminated armature core, and returns through another armature slot 180° from the first slot, and is then connected to a commutator segment *next adjacent* to its starting segment or 360° minus one segment. This second segment is then connected through a second loop to the third segment, and so on until the circuit is completed to the first segment (Illust 53). Thus it will be seen that all the loops are connected in series. Now, if brushes wide enough to contact two or more segments, are placed on the commutator 180° apart, and voltage is applied to the brushes, current will flow through all the loops except those shorted out by the two brushes. It will be noted that two distinct and parallel paths are provided for the current to follow, and that current flows in the same direction in all conductors passing before a pole piece. It will also be noted that the direction of current flow changes at the neutral position or between the magnetic fields.

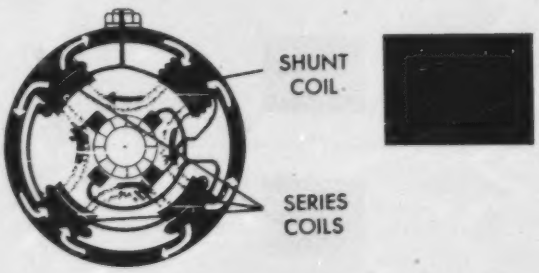
A more realistic diagram of the windings is shown in Illust. 54. Note that a lead of approximately 90° is provided on either side of the brush in order to place the brush midway between the sides of the loop and to effect a change of direction of current flow as the loop passes through the neutral position.




Illust. 53—Diagram of Armature windings.




Illust. 54




Illust. 55—Series shunt winding.

In the more commonly used four pole cranking motor, the armature is wound in the same manner but, since there are four distinct magnetic fields, the direction of current flow in the armature windings must be reversed four times in each revolution. This is done by spanning only 90° of the armature between the sides of each loop, and connecting the commutator segments opposite each other or 180° minus one segment. This procedure will cause the coils to be shorted out of the circuit at the commutating point because both ends of the coil are in contact with brushes of the same polarity.

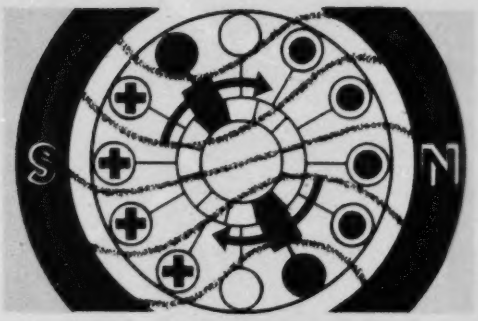
In the six pole unit used on larger engines, there are six distinct magnetic fields and the direction of current flow in the armatures windings must be reversed six times in each revolution. This is done by spanning only 60° of the armature between the sides of each loop and connecting to commutator segments 120° less one segment apart. This will also, bring both ends of the coil, under brushes of the same polarity.

In some applications provisions must be made to prevent excessively high free speed in in cranking motors. To prevent such excessive free speeds one or more of the poles is wound as a shunt as shown in Illust. 55. The magnetic field of the shunt coil remains constant regardless of armature speed and the greater counter voltage due to greater armature speed limits the current flow and, consequently, the top speed.

It should be noted that, although the neutral position is always half-way between the field poles, the current passing through the armature windings creates another magnetic field

which distorts the normal field between the poles as shown in Illust. 56. For this reason the actual neutral position is behind (in the direction of rotation) the center point on cranking motors and ahead of the center point on generators. Therefore, the brush location is set to compensate for this variation and to eliminate excessive sparking at the brushes.

It has been pointed out that cranking motors are low-resistant and high powered. Therefore, the amount of current used will be high. The number of amperes will, of course, depend upon the voltage and the power required, and will vary from 100 to 300 amperes or more.




CRANKING MOTOR LOAD
NEUTRAL

Illust. 56

# Ignition Circuit

The gasoline engines used in tractors and other farm equipment depends upon electricity to ignite the fuel and air mixture in the combustion chamber. In order for this ignition to take place, it is necessary to have a spark occur in the combustion chamber. This spark takes place when electricity jumps across the gap between the electrodes of a spark plug. This spark must occur at the proper time in the combustion chamber so that the burning fuel can exert pressure on the piston to cause the crankshaft to rotate.

The electrical circuit which provides this spark at the spark plug is known as the ignition circuit. The ignition circuit is different from the other electrical circuits we have discussed in that there is a permanent opening in the circuit at the spark plug. This means that if electricity is to flow past this point, it must jump this gap to complete this circuit. In order to understand how this can be done, we must examine the components of the ignition circuit.

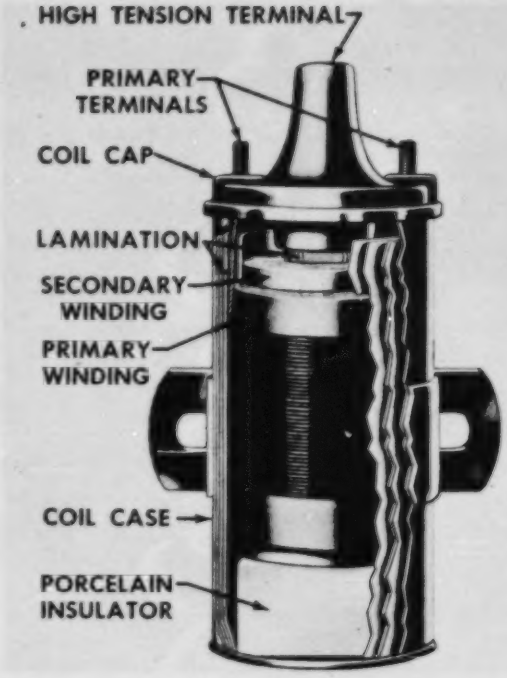
We know from Ohms law that the current flow in a circuit is a function of the voltage and the resistance. Since the air gap between the points at the spark plug is a high resistance in the circuit, we see that if any current is to flow at all, the voltage or pressure will have to be increased. In fact, the voltage will have to be increased substantially above that furnished by a battery or generator to make a spark jump the gap at the spark plug. It has been found that it takes 20000 volts per centimeter of air gap between needle points to make a spark jump.

## INDUCTION COILS

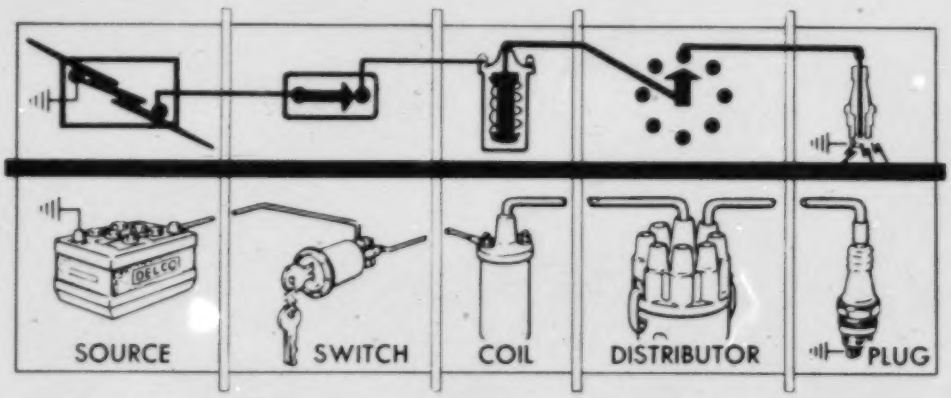
We learned from our study of electromagnetic induction that if we pass a current through a coil we can induce a voltage in a second coil wrapped around the first if we interrupt the current flow in the first coil. The voltage induced in the secondary coil is proportional to the relative number of turns in each coil. We see then that if we have only a

few hundred turns in the first or primary winding and the secondary winding has many thousands of turns of very fine wire, the voltage can be increased in the secondary winding many times higher than the battery voltage. The induction coil used in ignition circuits is constructed in this manner.

Illust. 57 shows a typical induction coil used in ignition systems. You will notice that in actual construction, the primary winding is on the outside of the secondary winding. When the current in the primary winding is interrupted, the voltage induced in the secondary winding can be as high as 25,000 volts. This voltage is high enough to cause a spark to jump the gap at the spark plug. With the use of an induction coil, along with a battery, a distributor, a switch, and the spark plug, we have an ignition circuit. (Illust. 58). The battery furnishes the current to the primary winding of the coil and on to the distributor in which is located a set of breaker points which interrupt the primary current at the right time to cause a spark to occur at the spark plug.




Illust. 57—Cut away of an induction coil.

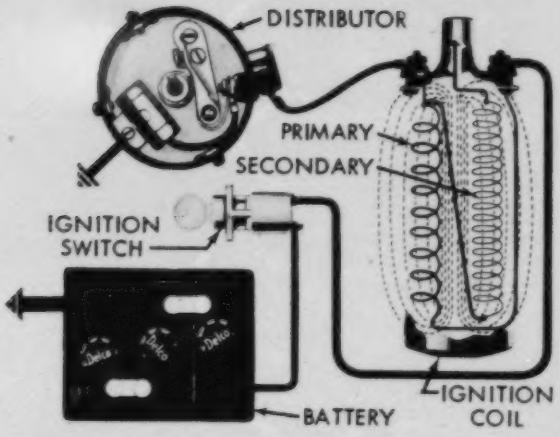



Illust. 58—Components of an ignition circuit.

## PRIMARY CIRCUIT

Illust. 59 shows the primary circuit of a typical ignition system. If the switch is closed, a current will flow from the battery through the primary winding of the coil to the distributor points and through ground back to the battery.

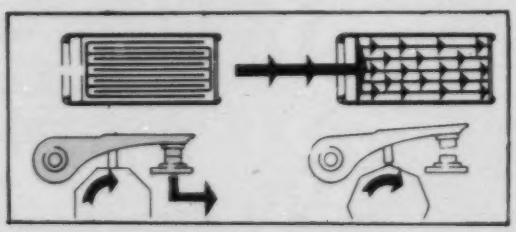
As the current starts to flow, the magnetic field around the coil is expanding. This, as we know, causes an induced voltage in the primary which is in the opposite direction to that of the current flow which tends to oppose the flow of current from the battery. This




Illust. 59—Primary circuit of ignition system.

causes a slight delay in the current flow reaching its maximum. This self-induction becomes an important factor when an engine is operating at high speed.

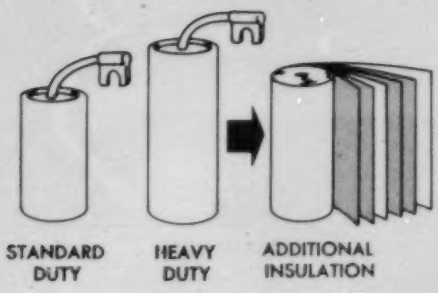
When the points open, the current in the primary circuit stops and the magnetic field collapses. When this happens, there is a self-induced voltage built up in the primary coil which tends to keep the current flowing. As we know, the more suddenly the current is interrupted, the higher will be the induced voltage in the secondary winding. Therefore, this self-induced voltage which is built up in the primary causes a spark to jump across the points, burning them. In addition, the current flow does not stop quick enough to induce the high voltage needed in the secondary circuit.



Illust. 60—Condenser action.

## CONDENSER ACTION

In order to overcome this, a device called a condenser is connected across the points. The function of the condenser is to absorb current flow momentarily to prevent arcing at the distributor points. (Illust. 60). When the points separate, the condenser absorbs the current momentarily, stopping the current flow across the points. This action builds up a higher voltage in the secondary. In addition, since the current is absorbed in the condenser, it prevents arcing at the points. It should be understood that current cannot flow through a condenser but only into it. The condenser is composed of two foil sheets which are separated by insulating paper and rolled up together. (Illust. 61). One of the foil sheets is grounded to the case of the condenser and the other is connected to the insulated lead at the other end of the condenser. Since the two foil sheets are connected only through the primary circuit, current cannot pass from one sheet to the other except to go through the primary circuit. With this situation, the primary current flows into the condenser when the points open. This charges up the condenser. When the voltage in the condenser gets higher than in the primary of the coil, it discharges back through the primary. In effect, there is an oscillating action between the condenser and the primary which continues until all of the remaining coil energy is dissipated.




Illust. 61—Construction of condenser.

## SECONDARY CIRCUIT

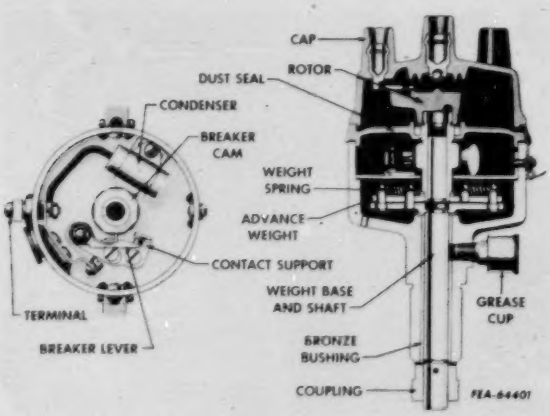
The induced voltage in the secondary coil builds up, when the primary circuit is interrupted, to whatever level is required to jump the gap at the spark plug. This may be anywhere from 4,000 - 20,000 volts, depending upon the conditions in the engine.

The secondary coil has one end attached to one end of the primary winding, (Illust. 59), and the other end is connected to the high tension terminal of the coil. A heavily insulated wire carries the current to the spark plug.

The secondary circuit is completed through the battery and primary circuit. Since the secondary voltage is so high, it is necessary to have much heavier insulation on the secondary wiring than on wire carrying low voltage, to prevent short circuits. The heavy porcelain insulator round the center electrode of the spark plug is there to prevent short circuits within the spark plug itself.

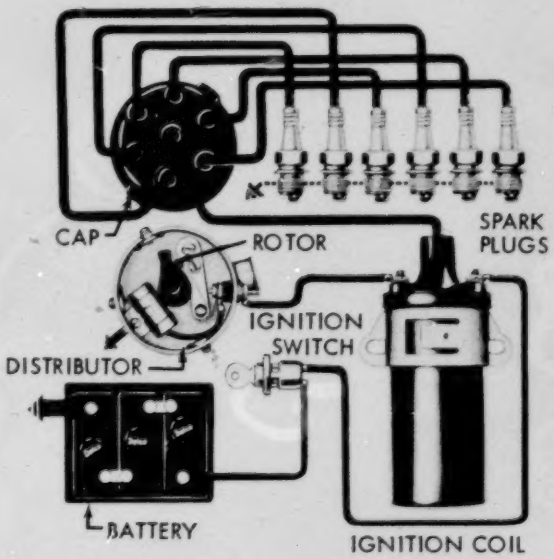
## DISTRIBUTOR

In order for the spark to occur at the right cylinder at the right time, the distributor includes a cam which opens and closes the points and also a rotor and cap which distributes the spark to the correct cylinder. The time when the spark occurs is controlled by the relationship between the cam and the points in the distributor. Adjustment of the ignition timing is accomplished by changing the position of the fibre actuating arm on the movable distributor point with respect to the lobes on the cam. This is done by rotating the body of the distributor with respect to the cam. Rotating the distributor body in the direction of cam rotation will retard the spark and rotating it in the opposite direction will advance the timing.




Illust. 62—Cut away of a distributor.

It is also necessary for best operation of an engine to advance the timing as the engine speeds up. This is done automatically in the distributor by means of a set of weights. (Illust. 62). Centrifugal force causes these weights to separate as the engine speeds up which shifts the cam ahead with respect to the breaker points thus advancing the timing. You will note also in Illust. 62 that the condenser is connected directly across the points so that when the points open, the current flows into the condenser as described above.

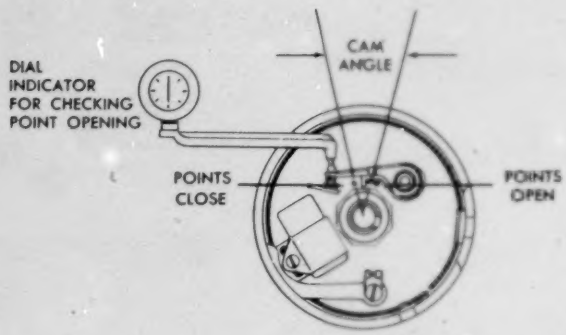



Illust. 63—Primary and secondary ignition circuit.

We see from our examination of the ignition system that there are actually two circuits, one a low voltage primary circuit and the other a high voltage secondary circuit. Illust. 63 shows a typical ignition circuit. The primary circuit is shown in red and the secondary in blue. You will note that the distributor rotor takes the high voltage current from the center terminal of the distributor cap and directs it to the various terminals near the edge of the cap. If the correct leads to the spark plugs are placed in these terminals according to the firing order of the engine, the sparks will occur at each plug in the right order.

As we know, the direction of the build up of voltage in a coil is dependent upon the direction the current flows through the primary circuit. The direction the high voltage current will flow in the secondary circuit is dependent upon how the coil is hooked into the primary circuit. It is a known fact that a

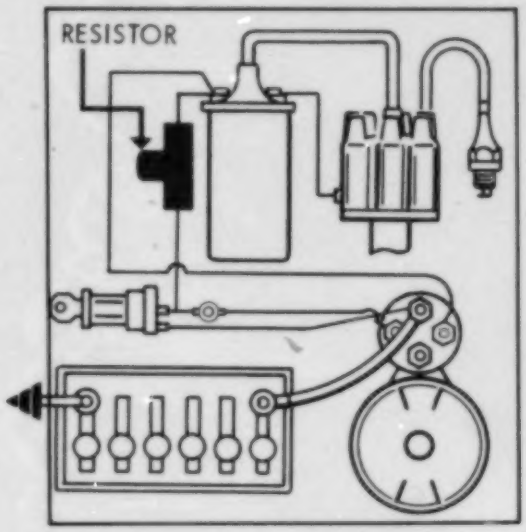
spark will jump more readily from a hot surface to a cool one than it will from a cool to a hot one. Since the center electrode of the spark plug is hotter than the grounded one, it is desirable to place the coil in the primary circuit so that the secondary current flow will be from the center electrode of the spark plug to ground. It takes about 5,000 volts less to make the spark jump from the center electrode to ground than in the reverse direction. For this reason, the primary terminals on the coil are marked (+) and (—). If the negative terminal of the battery is grounded, then the negative terminal of the coil should be attached to the distributor terminal. If the positive terminal of the battery is grounded, then the positive terminal of the coil should be connected to the distributor.




Illust. 64—Checking point opening with dial indicator.

## DISTRIBUTOR POINT SETTING

The amount that the distributor points separate as the cam opens and closes them is an important consideration which should not be overlooked. If the point setting is too wide, the points will not only open sooner, but will stay open longer which means that the build up time for the coil will be shorter. This can be a disadvantage at high speeds because the coil may not have time to build up enough voltage to fire the spark plug. If the point opening is too narrow, the points will open later and close sooner. While this increases the length of time the points are closed (cam angle) it also causes the rubbing block to contact the cam at a point where a slow rate of break occurs. The result is more arcing at the contact points and sometimes missing of the engine. It is, therefore, important that the point gap be set according to specifications for the application. When checking the breaker point opening, a dial indicator should be used, as shown in Illust. 64, to check the opening accurately. This is far better than trying to measure with a feeler gauge since the results are much more accurate especially if the contact surfaces of the points are the least bit pitted or irregular.




Illust. 65—Showing resistor in primary ignition circuit.

## RESISTANCE IN 12 VOLT SYSTEM

When a 12 volt system is used, it is a common practice to use an external resistance in the primary ignition circuit to reduce the voltage to approximately 6 volts. (Illust. 65). This resistance is in the circuit when the engine is running, but is shorted out of the circuit during starting. The cranking motor solenoid usually has a switch incorporated in it which shorts the resistance out of the ignition circuit when the cranking motor switch is closed. This gives full battery voltage on the coil for starting and then, when running, the resistance cuts the voltage back.

As we know, when the temperature of a resistor rises, its resistance value increases. With this external resistance at low speed, it is hotter because of the longer contact time. This means that its resistance will be higher



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at low speed than at high speed. At high speeds, this resistor then will be cooler due to the shorter contact time and will, therefore, permit more current to flow in the coil. This feature stretches out the performance of the coil and provides higher voltage at top speed. This helps to keep the engine firing at top speed and reduces danger of burning distributor points at slower speeds when contact time is the longest.

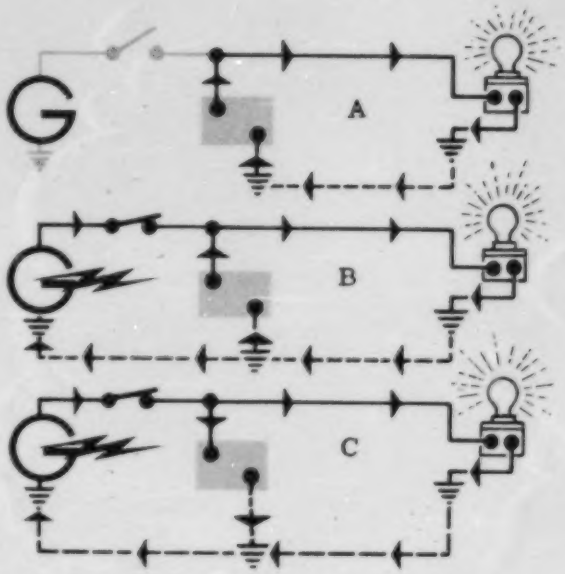
## Charging Circuit

We are familiar with the fact that a battery is a chemical source of electricity and is commonly used in electrical circuits on tractors and other farm equipment. We also know that there is a limit to the amount of electricity which can be drawn from a battery, and when that limit is reached, it will no longer produce current in the quantities needed. It, therefore, becomes necessary to provide another source of electricity to supplement and replenish the electricity furnished by the battery.

A storage battery can be recharged simply by reversing the flow of current through it. This action reverses the chemical activity in the battery so that it can again deliver current to the circuits attached to it. The generator is a device for converting mechanical energy into electrical energy. The generator cannot deliver any electrical energy, however, unless it is being driven by the engine so it is necessary to have the battery to supply the energy required for starting the engine. The generator can then take over and supply energy to operate the electrical system on the machine as well as recharge the battery.

Whether the energy required for the electrical system is supplied by the battery or the generator or both depends on the conditions under which the generator operates.

If the engine is stopped, the battery furnishes all of the energy since none can be furnished by the generator. Note that in Illust. 66, "A" the switch is open, separating the generator from the circuit. When the engine is operating at medium speeds, "B", the generator supplies part of the current and the battery supplies the rest. When the engine speed is increased, "C" the generator supplies all of the energy required for the electrical system and also energy to recharge the battery. It can be seen that if the battery is to be recharged, the generator must supply all of the energy for the electrical circuits.




Illust. 66—Showing three conditions of generator circuit with engine stopped, medium speed and high speed.

We see from Illust. 66 that the generator, a switch, the battery, and the load are all connected into a circuit or circuits and operate together. The battery furnishes current to the load when the generator cannot, and the generator picks up the load and recharges the battery when its speed picks up.



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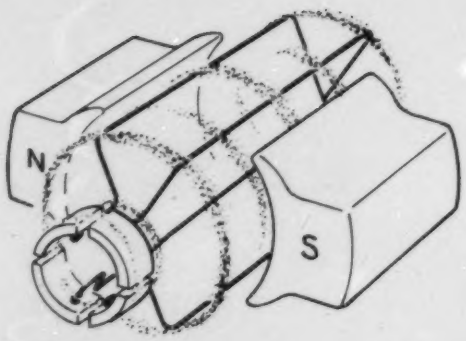
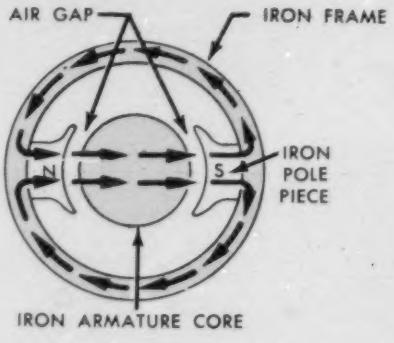
## SHUNT GENERATOR PRINCIPLES

In order to see how a generator functions in the system, let's take a closer look at what it does. As we learned from the principle of electromagnetic induction, a wire loop cutting through a magnetic field causes a voltage to build up in the loop and a current to flow if a circuit is attached to the ends of the loop. We also learned that a commutator must be used with brushes to reverse the current flow in the loop at the neutral point. See Illust. 26 under "Fundamentals of Electricity." Since one loop will generate only a very small voltage, it will have little value as a generator. However, if we add more loops and more commutator bars and connect the loops in series with each other, then the voltage generated would be added and more current can then flow (Illust. 67). This, then, is the basis of the construction of the rotating member of the generator which is called the armature. The armature is wound with a number of coils of wire on a soft core so that there are a large number of conductors to generate voltage. These coils are connected in series to the commutator bars in the same manner as the armature for the cranking motor. In the case of the generator, the wire used is considerably smaller because it is not required to carry such a high current.



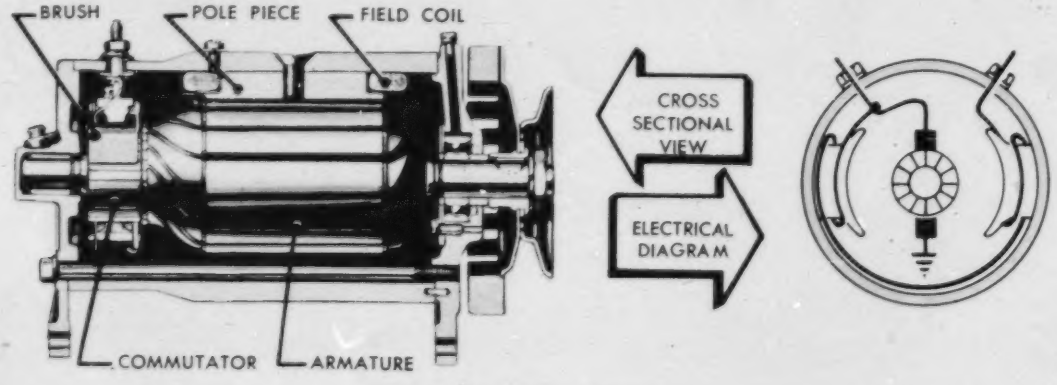

Illust. 67—Showing several loops in armature.

In order to strengthen the field in which the armature rotates, an iron frame is placed around the poles which, as we know, strengthens the magnetic field by providing a conducting path for magnetic lines of force between the poles. See Illust. 68.




Illust. 68—Showing magnetic lines of force traveling in frame.

In addition, the field poles are soft iron with field coils wound around them so that the strength of the magnetic field can be still further increased. The current for the field coils is obtained from the armature as it rotates. Illust. 69 shows the modern generator and the electrical diagram of the unit. We see




Illust. 69—Cross Section of Generator.



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then that the three basic fundamentals for developing current and voltage are being used in the construction of the generator, namely, strength of magnetic field, the number of conductors on the armature and the speed of armature rotation.

We learned that the speed at which a conductor cuts lines of force affects the voltage which is built up in the conductor. This being true, the faster the armature of the generator turns the higher the voltage will build up. This means that the voltage developed within the generator will climb to any value necessary to overcome the resistance in the attached circuits, providing the speed of the armature is sufficient. If the total resistance in the attached circuits is low, generator voltage will be low, if the attached circuits total resistance is high, generator voltage will be high. Since the field coils in the generator and many of the external loads can be damaged by excessively high voltage, some method of voltage control is necessary. This voltage control is handled by means of an external unit called a voltage regulator.

Current flow through the generator is the result of the voltage developed in the armature coils. The amount of current flow in the armature and in the attached circuits depends upon the voltage developed and the resistance in these circuits. If the total resistance of the attached circuits is high, the generator voltage will be as high as the voltage regulator will permit, and the current flow will be low. If the resistance in the attached circuits is low, the current flow will be high provided the generator speed is sufficient. Armature overheating can result from the high current flow.

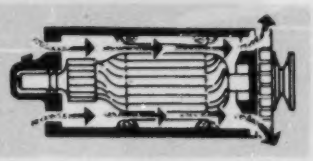
Overheating of the armature can damage the insulation and varnish used to bind the conductors in the armature slots. The soldered connections at the commutator bars can also be melted by excessive heat. To prevent this condition, an external unit called a current regulator is used to limit the current flow in the generator.

There is another source of heat in the armature which must be considered and that is "iron loss." The iron core of the armature acts as one large conductor which cuts lines of force, and generates voltage in the core itself. The resulting current flow is called "eddy currents." These currents produce heat which is added to the heat generated by the coils themselves. To reduce the eddy current in the core as much as possible the iron core of the armature is laminated. This procedure prevents large voltages building up and the eddy currents are kept small and less heat is developed in the armature (Illust. 70).

EDDY CURRENTS CREATE HEAT

Illust. 70—Eddy currents create heat.

PLACING A FAN ON THE GENERATOR DRIVE PULLEY



Illust. 71—Generator ventilated by fan.

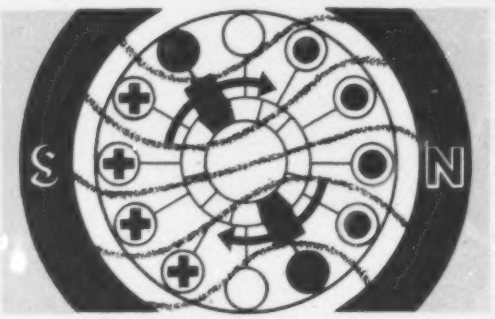
We see from this that one of the limiting factors in generator output is heat and must be considered in the design of the generator. Many generators have provisions for passing air through them to help carry the heat away. This is often done by placing a fan on the generator drive pulley which draws air through the generator (Illust. 71). Air may also be forced through a generator from an external source through a blast tube. This will cool the generator and permit a higher current rating than if it were not cooled.

## ARMATURE REACTION

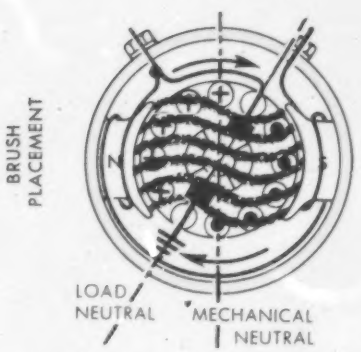
We learned when studying electromagnetic induction that when a conductor cuts through lines of force that these lines of force become bent causing the neutral point to shift from the mechanical neutral point which is half

way between the poles. This shifting of the neutral position is due to what is called "armature reaction."

In the case of the cranking motor, we learned that the "load neutral" point is shifted ahead of the mechanical neutral point because




CRANKING MOTOR LOAD NEUTRAL




GENERATOR LOAD NEUTRAL

Illust. 72—Load neutral

the lines of force bend around the trailing edge of the armature conductors. In the case of the generator, the lines of force are bent around the leading edge of the armature conductors which causes the load neutral point to shift ahead of the mechanical neutral point. See Illust. 72.

Inasmuch as the current flow in the armature conductors reduces to 0 at the load neutral point, this means that commutation should take place at this point. Since no current is flowing in the coil at this point, the coil can be shorted out of the circuit without causing arcing at the brush. In view of this, the brushes should be moved to the load neutral position for best operation. The actual position of this ideal commutating point is affected by the speed of the armature and the load applied. This means that in actual operation, the load neutral point is constantly changing. For this reason, a brush location is chosen which will be the best average position and cause the least arcing under the most usual operating condition.

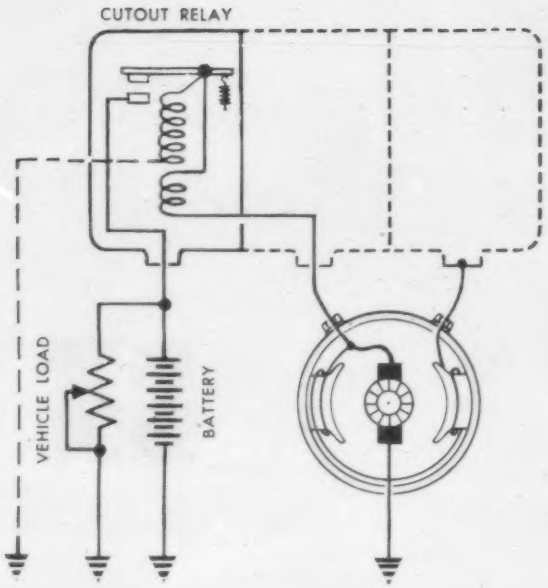
In actual practice the brushes themselves are not in the load neutral position but the armature coils are attached to the commutator segments which are under the brushes when that coil is in the load neutral position.

## GENERATOR CIRCUITS

Now that we have seen how a generator converts mechanical energy into electrical energy, let's examine the electrical circuits in a standard two brush generator to see how the unit operates. There are actually three circuits which involve the generator directly. One is the charging circuit (Illust. 73) which starts at the insulated brush of the generator, out through the battery to ground and back through the ground to the grounded brush in the generator. The second circuit is the load circuit which starts at the insulated brush and out to the load and back through the ground (usually the frame of the machine) to the grounded brush in the generator. The third circuit starts at the insulated brush and passes through the field coils, the regulator, and back to ground.

### CHARGING CIRCUIT

If we examine the charging circuit shown in Illust. 73 more closely, we see that if the circuit went directly from the insulated brush in the generator to the battery, a circuit would be complete regardless of whether the generator is running or not. This means that the battery would discharge through the generator whenever the generator is stopped. In order to prevent this happening, an automatic switch is inserted in the circuit called a cut out relay. This cut out relay is composed of a set of contact points, one of which is stationary and is connected to the line to the battery.




Illust. 73—Circuit diagram of two brush generator with cut out.

The other point is movable and is mounted on an arm called an armature which is pivoted. A spring attached to this armature keeps the points separated so that current cannot flow unless the points are closed. Just beneath the armature is a soft iron core. On this core are wound two coils. One is composed of a few turns of heavy wire which is connected in series with the charging circuit and through which all current in charging circuit must flow. The second coil is composed of a large number of turns of fine wire and is connected as a shunt with one end grounded. See Illust. 73.

When the generator is stopped, the spring tension holds the points open so that the battery cannot discharge through the generator. As the generator picks up speed, voltage builds up in the cut out coils and current flows through both coils which are now in series to ground. This action magnetizes the core which, when the voltage gets high enough, will pull the points closed and allow current to flow to the battery. The coil with the fine winding now becomes a shunt coil and carries a small amount of current which goes directly to ground without going through the battery.

When the generator slows down to a point where the voltage of the generator is less than that of the battery, the current starts to flow back through the generator. When this happens, the current is reversed in the heavy series winding. However, since the fine shunt winding still has the same end of the coil grounded, the current flowing through it will be in the same direction as before. Since the direction of current flow in the series winding is reversed, its magnetic field is also reversed and will oppose the field of the shunt coil. This weakens the field to a point where the spring on the armature can separate the points and stop the current flow.

The voltage at which the points close in the cut out relay can be adjusted by changing the tension of the spring on the armature. It is important that this adjustment be made so that the "cut in" point is not right at the idle speed of the engine. The reason for this is that engines do not idle at a uniform speed therefore, if the "cut in" point is right at idle speed the points will tend to open and close rapidly, causing burning of the points in the relay. The "cut in" point should be at least 100 rpm above or below engine idle speed to avoid this.

### LOAD CIRCUIT

The load circuit starts at the insulated brush in the generator, passes out through the cut-out relay, through the load, and back through ground to the grounded brush in the generator. This places the load in parallel with the generator and the battery so that current can be supplied by either the battery or the generator as described on page 35.

### FIELD CIRCUIT

The shunt field circuit is the third circuit which starts at the insulated brush in the generator, passes through the series field coils and through the regulator to ground. This circuit causes the field strength to increase as the generator speed increases and the voltage builds up in the generator.

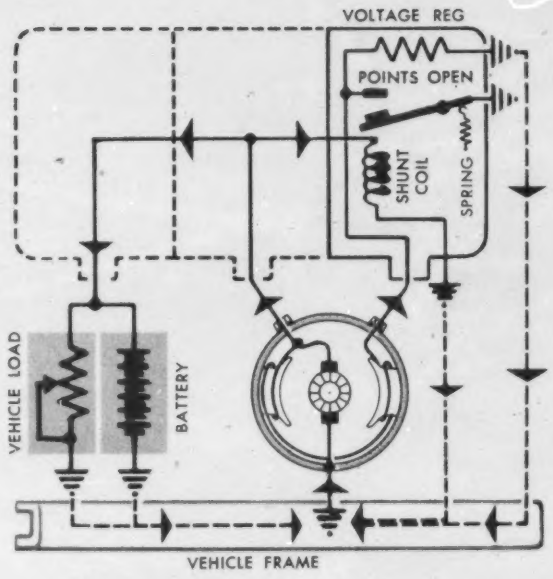
## CONTROL OF GENERATOR OUTPUT

We have seen from the foregoing that the output of the generator depends upon the speed of the generator and the amount of load in the circuit. If there is low resistance in the charging and load circuits, the current flow from the generator will be high provided the speed of the generator is great enough. We also know that if the speed of the generator is high enough, the voltage will rise to almost any height required to overcome high resistance in the circuit. This means that in order to prevent high voltages from being impressed on load and charging circuits, it is necessary to have some control over the generator voltage.

### VOLTAGE REGULATOR

If a generator has a control on the maximum speed at which it can operate, such as is the case on tractors which have governed engine speed, this will serve to protect the generator from becoming overloaded. However, it will not prevent the voltage from becoming too high. In order to prevent high voltage from building up to damaging levels, it is necessary to provide some means of controlling the voltage. This is done by an external unit called a voltage regulator.

The function of the voltage regulator is to control the strength of the magnetic field in the generator which, as we know, will control the voltage built up in the generator. The voltage regulator, like the cut out relay, has a voltage sensitive coil of fine winding on a core and a set of points which are held closed by a spring. This voltage sensitive shunt coil is connected across the generator brushes so that full generator voltage is impressed on it at all times, (Illust. 74). As the voltage builds up in the generator, the soft iron core of the voltage regulator becomes magnetized to a point where it pulls the points apart. When this happens, the field current cannot go directly to ground, but must pass through a resistance first. This reduces the field current, and therefore, weakens the magnetic field between the field poles. This causes a reduced current and voltage in the armature circuit. This action also reduces the strength of the magnetic relay in the regulator and allows the points to close. The voltage again starts to



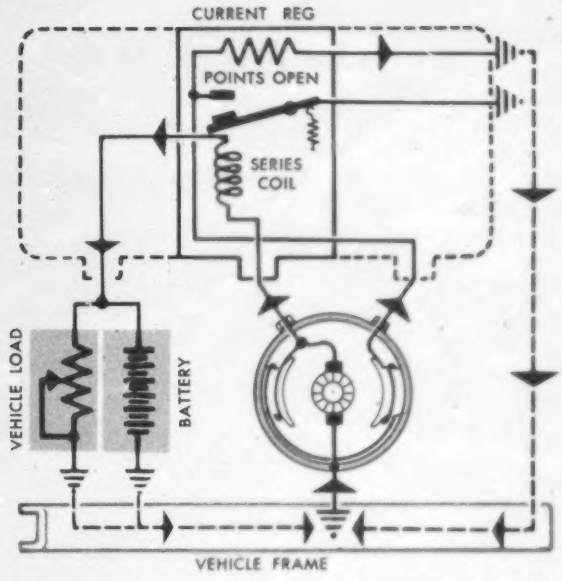

Illust. 74—Circuit diagram showing voltage regulator only.

climb to a point where the points open. In actual operation, the voltage regulator points open and close rapidly and are said to vibrate. The vibrating action of the points is so rapid that a voltmeter will register only the average voltage developed. With the voltage regulator in the field circuit, the voltage is held down to safe levels and prevents damage to units in the load circuit and also prevents overcharging the battery.

Since the voltage regulator permits high current to flow as long as the voltage is below the level set by the regulator, the battery can be charged at a high rate when the battery is low, and will cut down the rate when the battery becomes charged and its resistance is high. This will reduce the tendency for the battery to give off gasses and will, therefore, minimize the need for adding water to the battery.

### CURRENT REGULATOR

The voltage regulator cannot control the current output of the generator if the resistance in the load and charging circuits is low, since the generating voltage is below that set by the regulator. If the speed of the generator is high enough, the current flow may be so great as to cause overheating of the generator. In order to protect the generator from such overloads, a current regulator is used to limit the current flow to safe levels.




Illust. 75—Circuit diagram showing current regulator in circuit.

Illust. 75 shows a current regulator in the circuit. The current regulator is similar in its operation to the voltage regulator, except the coil which opens the points is in series with the armature circuit and all current except the field current must pass through it. This is a heavy coil and it causes the points to open which places a resistance in the field circuit and thus reduces the current output of the generator. In this manner, both the voltage and the current can be controlled within safe limits.

In actual practice, the cut out relay, the current regulator, and the voltage regulator are placed together in one unit. Illust. 76 shows the circuit diagram of the so-called three unit regulator and how it is connected into the circuit. You will notice that there are three terminals on this regulator, one marked "F", one marked "Gen" and one marked "Bat". To connect the regulator into the circuit, a lead is attached to the field terminal on the generator and to the "F" terminal on the regulator. The armature terminal is connected to the Generator terminal on the regulator and the lead from the battery through the ammeter is connected to the battery terminal of the regulator.

You will note in Illust. 76 that there is a field series winding wound on the core of the voltage regulator in addition to the shunt winding. This coil is only a few turns of relatively heavy wire which is also voltage sensitive and helps to open the points. This coil serves to increase the rate at which the points vibrate and thus keeps the voltage more constant.

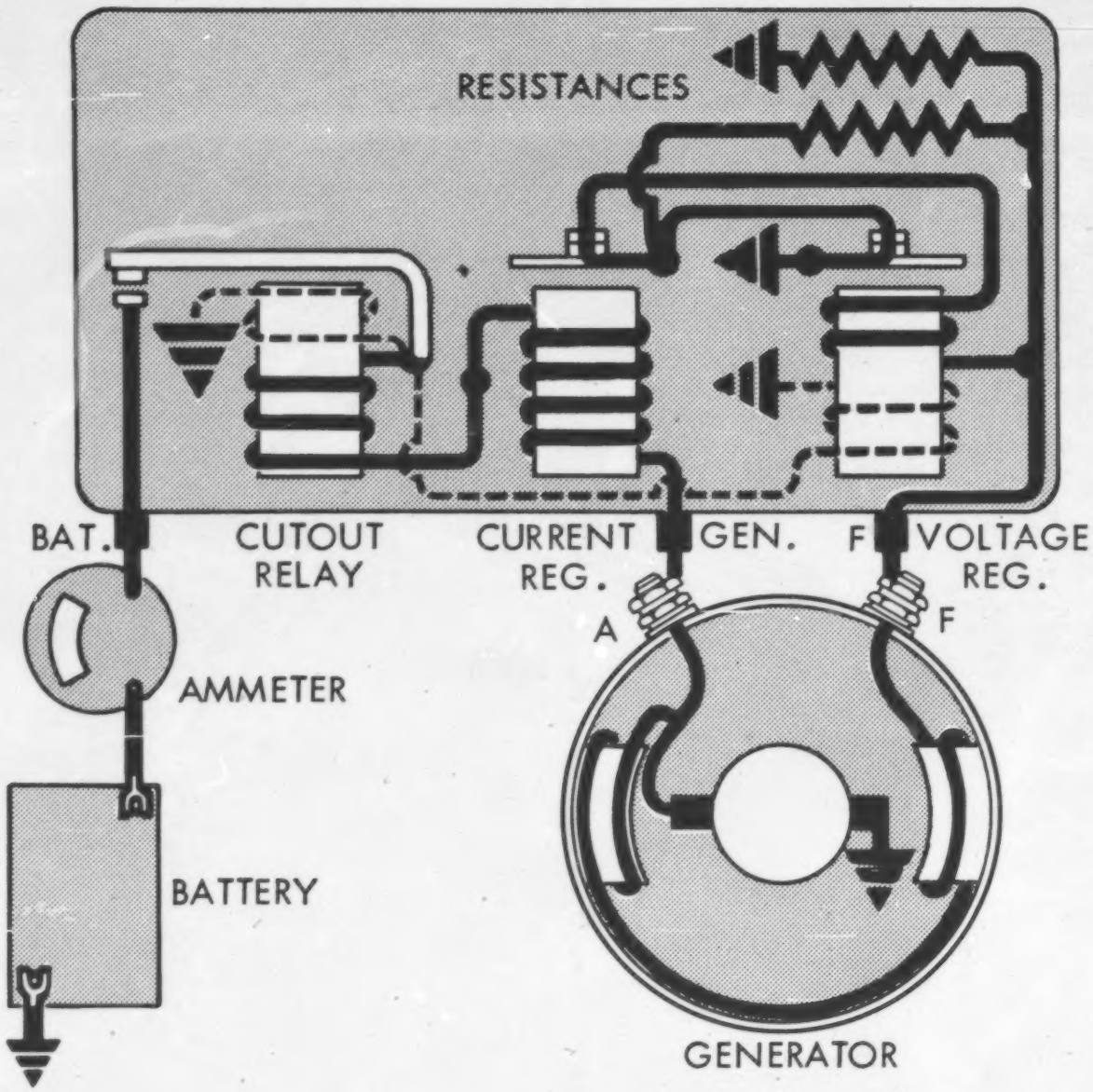
Note that there are two resistances connected in parallel in the field circuit. When the current regulator points open, the field current flows through both resistances in parallel to ground. This places less resistance in the field circuit than when the voltage regulator points open. In this case, the field current must pass through one resistance to ground. This is a desirable situation since the field current needs to be reduced only slightly to protect the generator from overheating, but needs to be cut down drastically to prevent overcharging a fully charged battery.

## COMBINATION CURRENT AND VOLTAGE REGULATOR

Another type of regulator which is used on many tractor applications is what is called a combined current and voltage regulator. This regulator is a two unit type incorporating a cut out relay and a combined current and voltage relay which has three windings on one core, one set of points, and one resistance. See Illust. 77.

You will notice from the circuit diagram that there is a series winding (heavy red) on the regulator core along with a shunt winding of many turns of fine wire (dashed red) plus a third series field winding (solid blue). This makes the regulator sensitive to both voltage and current at the same time.

You will notice also that there is a fourth terminal on the regulator which is marked "L". This terminal is connected to the stationary point on the cut out relay. This extra terminal permits current from the generator to be diverted directly to the load without passing through the regulator. This permits additional load to be placed on the generator without affecting the regulation of the charging

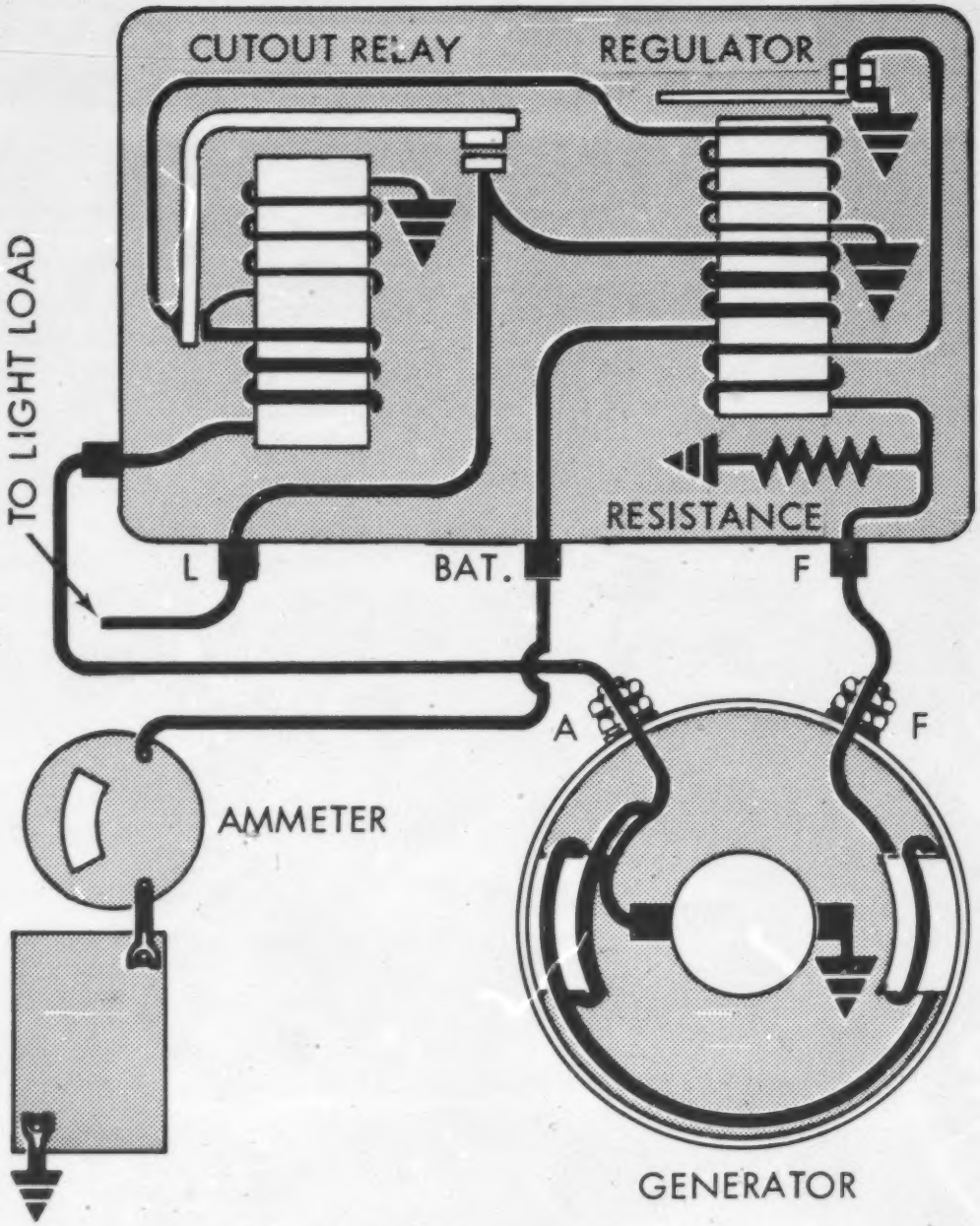



Illust. 76—Circuit diagram of three unit regulator.

current to the battery. When the generator is not in operation, the electrical load is supplied by the battery through the series winding of the regulator.

It is important that all light loads such as lights, ignition, etc. be attached to the "L" terminal in order not to interfere with regulation. Any load such as horns which individually may exceed the capacity of the generator should be connected directly to the battery side of the ammeter because heavy currents cannot be drawn from the battery through the series winding without considerable loss of voltage.

The field series winding on the regulator might be considered an accelerator coil in that it causes the points to vibrate more rapidly. When the contact points are closed, the




Illust. 77—Circuit diagram of combined current and voltage regulator.

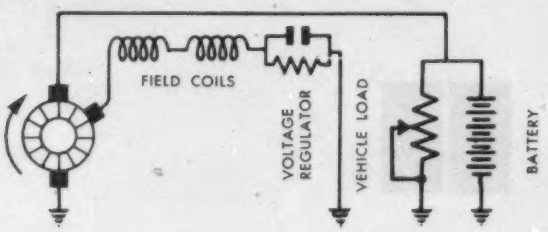
magnetic field of this winding aids the other two but when the contact points open, its magnetic field collapses immediately. As we know, when a magnetic field collapses, a counter voltage is built up in the coil with a reversed magnetic field. This field then bucks that produced by the other windings and rapidly reduces the attraction for the armature of the regulator. This action accelerates the vibration of the armature in opening and closing the points which results in a more accurate generator control.

## SPECIAL GENERATOR CIRCUITS

So far, we have discussed the principles of operation of the shunt type generator and the method of developing voltage in these units. There are other types of generators also which have been developed for specific applications. These generators use the same basic principles of operation as the shunt type with only slight variations or additions made to fit the application. Examples af these are the Third Brush, Interpole, Bucking Field and Split Field types.

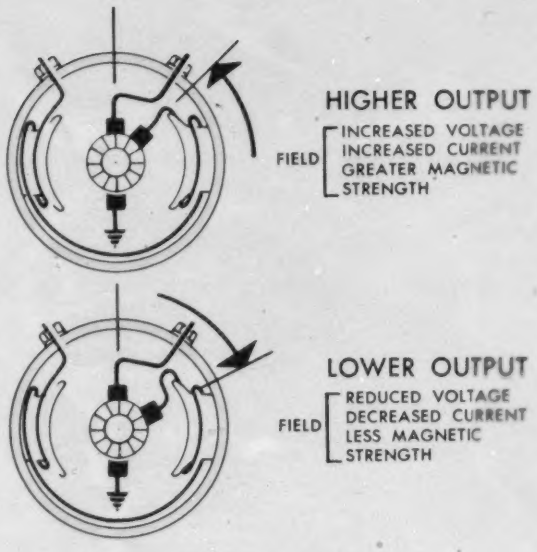
### THIRD BRUSH GENERATORS

The third brush type generator is similar in design to the shunt type except that it uses three brushes instead of two. The two main brushes are located at the neutral point where maximum voltage is developed. The third brush is located at a point between the main brushes. (Illust. 78). The purpose of this third brush is to take current off the commutator to feed the field coil windings.

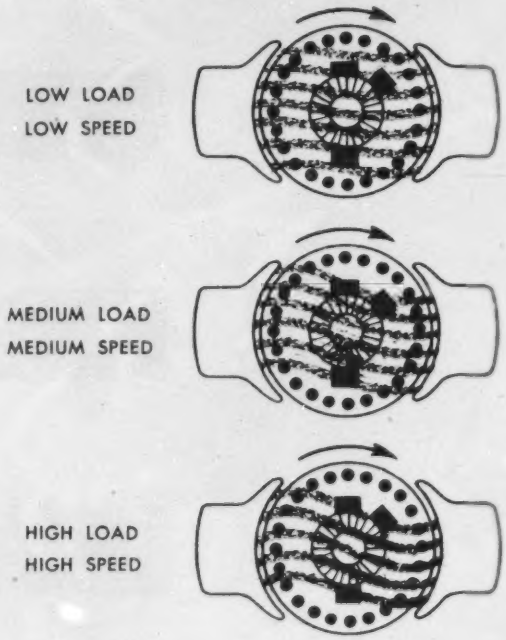



Illust. 78—Circuit diagram of 3rd brush generator.

Since the armature coils are connected in series, the maximum voltage will be across the main brushes, since the maximum number of coils are in the circuit. When the third brush is added, the voltage will be less between the third brush and the grounded brush, since fewer armature coils are in the circuit. The voltage which will be present at the third brush will depend upon the position of the third brush. The closer it is to the main insulated brush, the higher the voltage and thus the higher the field current will be. The farther the third brush is moved away from the main insulated brush, the lower will be the voltage, since fewer armature coils will be in the circuit. This action is just like the storage battery. The more cells we place in series with each other, the higher the voltage is developed.

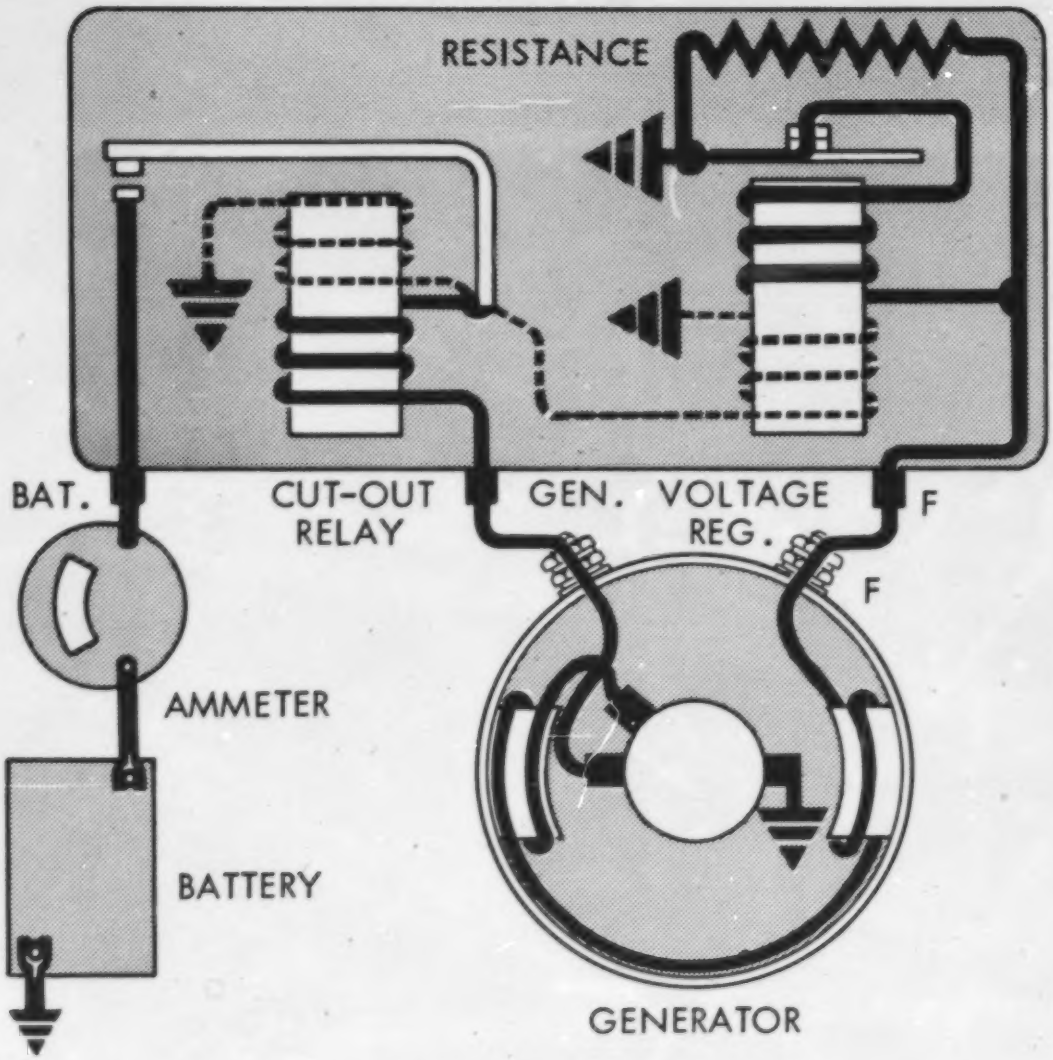



Illust. 79—Showing different positions of third brush and resulting output.




Illust. 80—Showing armature reaction at different speed of third brush generator.

Most third brush type generators have the third brush adjustable so that it can be moved, and thereby adjust the generator field strength, which in turn controls the output of the generator. See Illust. 79.

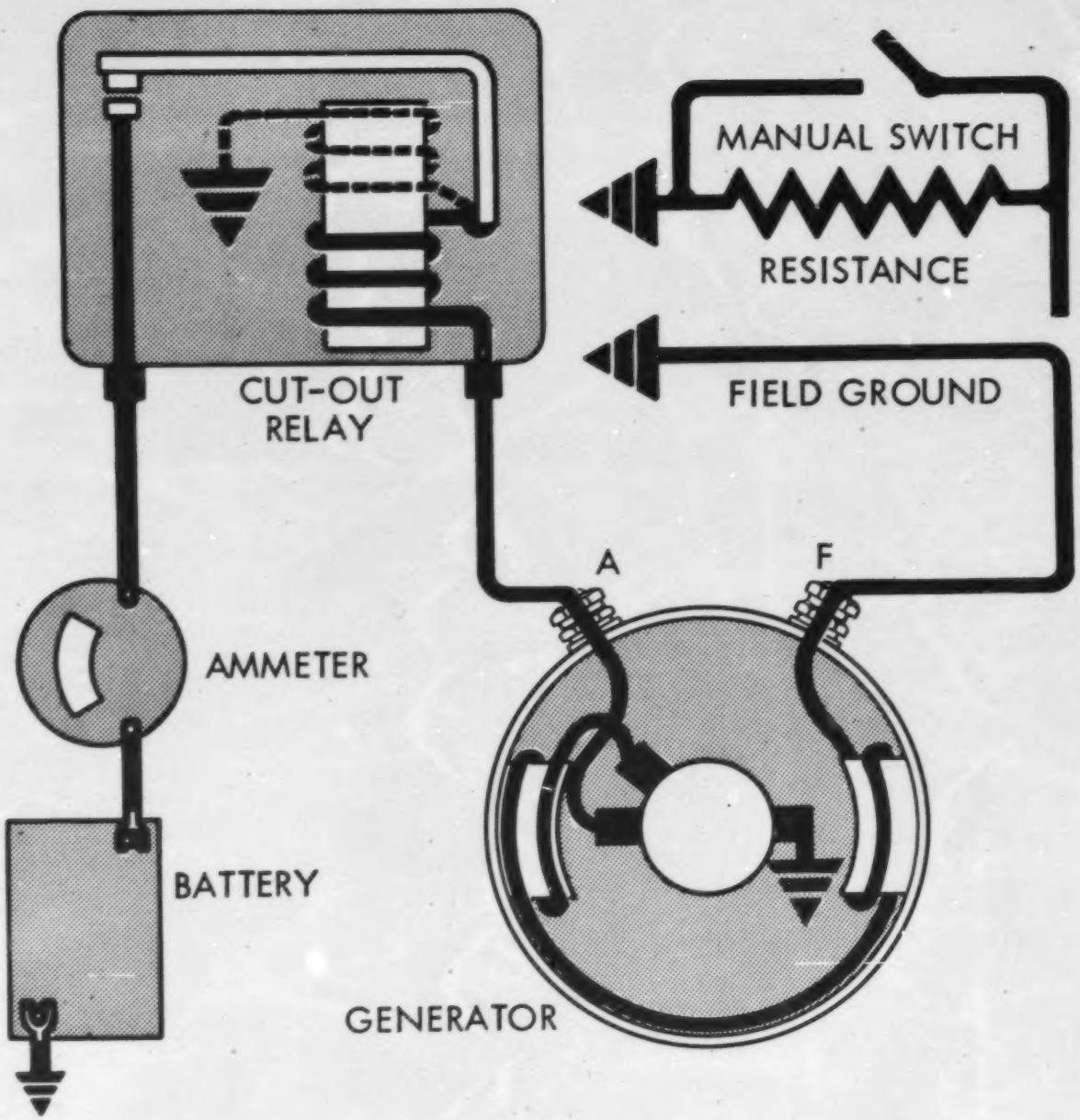



Illust. 81—Circuit diagram of third brush generator and vibrating regulator.

In the discussion of armature reaction, we learned that the field becomes distorted due to the armature cutting lines of force. This causes the neutral position to shift. As the speed and load on the generator increases, more distortion in the direction of rotation takes place.

When this happens in a third brush type generator, we see from Illust. 80 that, as the speed and load increase, the lines of force which are cut by the conductors between the third brush and the grounded brush are decreased. This means that the voltage will be decreased due to the distortion of the magnetic field. This automatically reduces the output of the generator.

Therefore, the third brush type generator can regulate its own current output without a current regulator. A voltage regulator is needed however, to control the voltage in the main circuit because this voltage is not affected by the action of the third brush. See Illust. 81. The voltage regulator used with this generator operates in a similar manner to those previously described.




Illust. 82—Showing manual switch in field circuit.

### Manual Control of Third Brush Generator Output

On some early applications of the third brush generator, a manual method of controlling field current was employed. This consisted of a resistance placed in the field circuit to reduce the field current and thus reduce the output of the generator. A manual switch was placed in parallel with this resistance so that when the switch was closed, the resistance was shorted out and maximum field strength was obtained. (Illust. 82). This type of unit has been used in applications where lights were the principle load in the circuits. In this case, the manual switch is incorporated in the light switch. When the lights are turned on, the resistance is shorted out of the field circuit

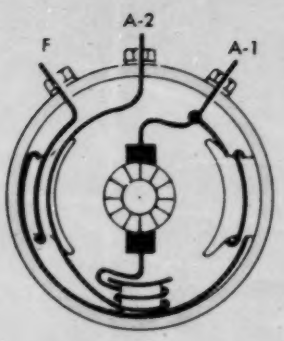
and maximum output of the generator is obtained. When the lights are turned off, the switch is opened and the resistance is then back in the field circuit. This reduces the generator output and prevents excessive battery overcharge and high voltage.

### CONCLUSION

The third brush type generator is a low capacity generator which has been used extensively in the past and is still used in applications where a high current output is not required. This type of generator is not suitable for high speed operation because the output drops off rapidly at high speed due to armature reaction.

## INTERPOLE GENERATORS

The interpole generator is one that has, as the name implies, a third pole mounted between the other two. (Illust. 83). The purpose of this interpole is to create another magnetic field which will neutralize the field produced by current flowing in the armature and thus straighten out the lines of force between the field poles. In other words, it overcomes the effect of armature reaction in distorting the field. This interpole is a narrow pole piece mounted on the generator frame between the two regular poles. It is wound with heavy bar copper since all the armature current goes through this winding. The number of turns in the interpole coil is calculated to produce enough ampere turns in the opposite direction to offset the magnetic field created by the

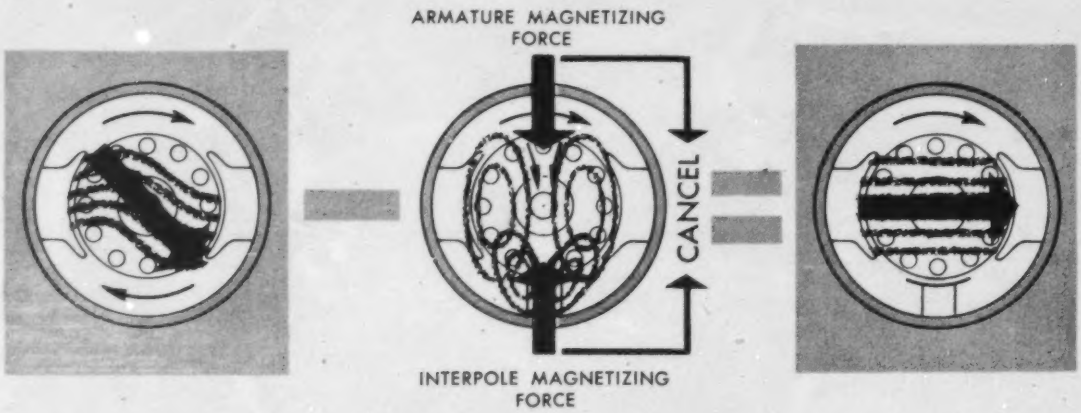



Illust. 83—Interpole generator.

current flow through the armature. Since the amount of current flowing through the armature and the interpole is always the same, the right amount of correction is always present to nullify the armature reaction and allow the normal magnetic field between the poles to remain in a straight line. See Illust. 84.

Because no field distortion exists when the interpole is used, it becomes necessary for the brushes to be exactly at the mechanical neutral position rather than the advance position as was found practical with regular generators.

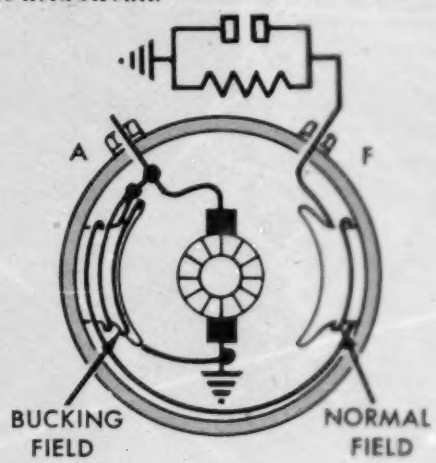
The advantage of the interpole generator is that the commutation can take place when the coil in the armature is carrying no current and thus reduce arcing at the brushes. It has been found that where high speeds and high current are a factor, that installation of an interpole generator can increase brush life as much as two to eight times over similar generators without interpoles.




Illust. 84—Showing interpole correction for armature reaction.

## BUCKING FIELD GENERATOR

With some generator applications where an extremely wide range of speeds is required, it becomes a problem to control the voltage with normal voltage regulation. At very high speeds, only a very weak field current is required to produce the needed voltage. The residual magnetism of the pole shoes is enough to produce voltage but this voltage cannot be controlled and the voltage in the main circuit will continue to climb even though the voltage regulator has the resistance in the field circuit.

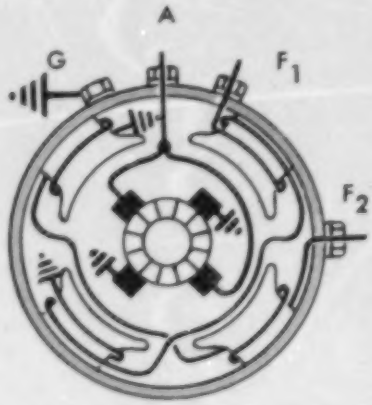



Illust. 85—Bucking field generator circuit diagram.

This type of problem can be overcome by the use of a bucking field coil. (Illust. 85). This is a shunt coil of high resistance wound on one pole piece and connected directly across the brushes. This winding is connected in a reverse direction to the normal field winding and has an opposing magnetic effect to it. At low speeds, when the normal field current is large, the opposing effect of the bucking field is not great in proportion to the main field. At higher speeds, when the current in the main field circuit is reduced by the voltage regulator, the opposing effect of the bucking field is greater than the residual magnetic field and practically all of the magnetic lines of force are cancelled. Thus, the current flow through the main field coils can be controlled by the regulator and the effects of the residual magnetism can be controlled by the bucking field, and normal generator voltage can be maintained. The purpose of the bucking field, is therefore, to aid in regulation.

## SPLIT FIELD GENERATOR

Under some operating conditions, where slow speed of the generator prevails for extended periods, the load circuit may exceed the output of the generator. Under these conditions, the battery must supply the current and will soon run down. In order to increase the output of the generator, it is necessary to increase the field strength. This would require increasing the field current in a standard generator. The regulator points cannot stand increased current however, because they burn so rapidly when they vibrate.




Illust. 86—Split field generator.

In order to get around this problem, the split field generator was developed. This, as the name implies, is a generator that has two field circuits and two sets of brushes. (Illust. 86). You will also notice that there are four pole shoes which will give approximately twice the field strength. Each field circuit is controlled by its own voltage regulator so that the field current across the regulator points is no higher than normal regulation and thus are not burned.

This type of generator is more costly and therefore, is not used except in special applications where engine idling periods are long and a standard generator cannot put out enough current to keep the battery charged.

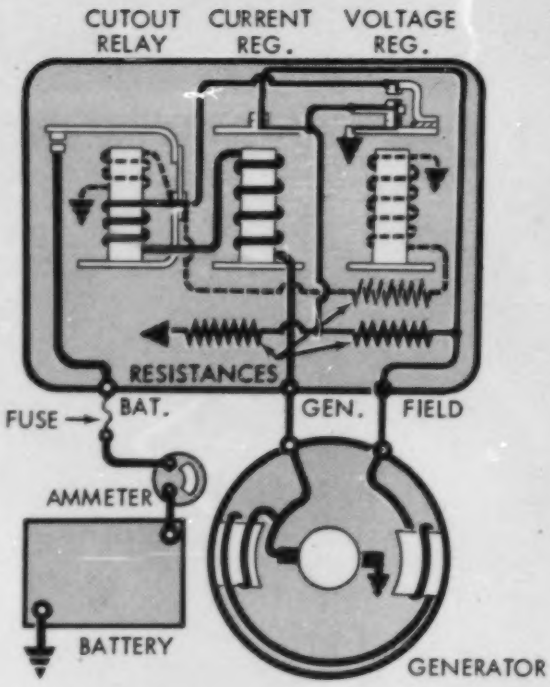
## DOUBLE CONTACT REGULATORS FOR GENERATORS

The vibrating contact points in regulators have a very definite limitation as to the amount of field current they can carry. As they open and close many times per second, they make and break the field circuit of the generator. Each time the points open, an arc occurs. This arcing burns the points even though they are made from the best materials known.

In order to prevent rapid burning of the points, it is necessary to keep the field current down to safe limits. In general, on six volt systems, a maximum of two amperes is allowed in the field circuit. On twelve volt systems, a maximum of 1½ amperes is allowed. On 24 volt systems, one ampere is permissible. This means that the regulator is a very definite limiting factor in the design of generators.

The limitation of the field coil current that can be handled by the vibrating points has, to a small degree, been offset by a new voltage regulator design which controls generator voltage by inserting resistance in series with the field circuit in two steps. (Illust. 87). In step one, a resistance of low value is inserted in the usual manner. When the voltage climbs to a predetermined value, step two shorts out the entire field circuit so that no current flows in the field coils.

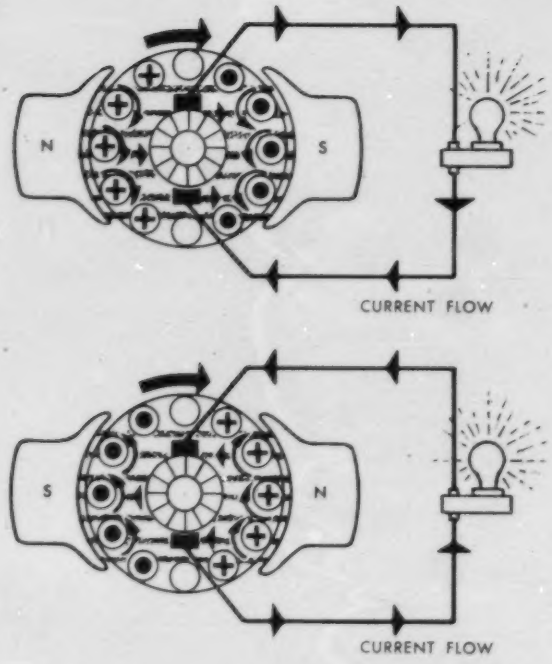
This decrease in the resistance of the field coil circuit permits slightly higher field currents. Higher field current means that the generator will develop regulated voltage at a lower speed, and if the design of the generator can stand it, higher output.




Illust. 87—Circuit diagram of double contact regulator.

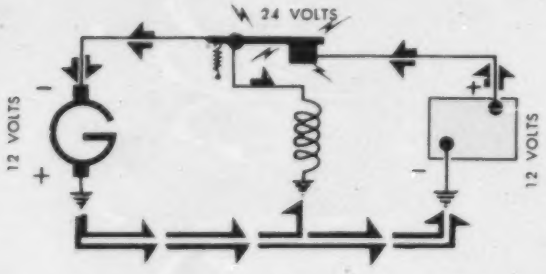
## POLARITY OF A GENERATOR

The polarity of a generator determines the direction of current flow from the generator to the external circuits. As we know from our study of Electromagnetic induction, the direction of current flow in a conductor which is cutting lines of force, is determined by the direction the conductor is cutting through and the direction of the flow of magnetic lines of force between the pole shoes. It can then be seen from Illust. 88 that if the North pole shoe is changed from the left to the right side, that the direction of current flow in the armature circuit is also reversed. We know that the magnetism in the field poles is created by current flow through the field coils. The direction the current flows through the coils, determines the polarity of the pole shoes. The residual magnetism and the polarity of the pole shoes will remain the same as was induced from the magnetism of its field coil, the last time current was passed through it. From this, we see that generators can build up voltage which will cause current to flow in either direction depending upon the residual magnetism in the poles. In order for a generator to function properly, the polarity of the generator must be the same as that of the battery. Illust. 89 shows what will happen if a generator is operated with reverse polarity in a battery charging circuit. Since current flows from positive to negative, we see that the generator is now in series with the battery so that as soon as the generator develops enough voltage to close the cut out points, the voltage of the




Illust. 88—Showing direction of current flow when polarity is reversed.

battery is added to that of the generator, producing approximately double the regular system voltage. This high voltage and the resulting high current which will flow through the regulator will cause the points to try to open, creating an arc which will weld the points together instantly. In addition, due to the effect of the shunt winding on the cut out relay, the cut out relay points may start to vibrate. If this happens, these points may also be welded together and a high discharge current will rapidly discharge the battery.

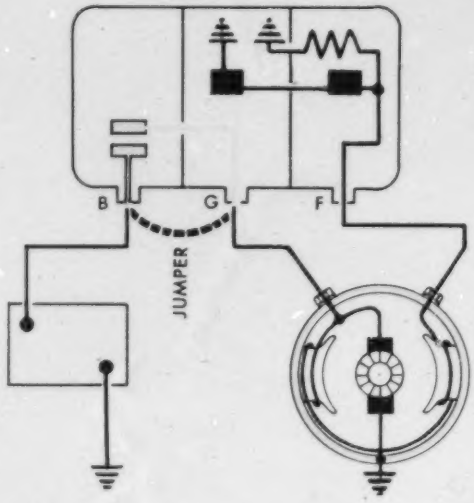



Illust. 89—Showing effect of reversed generator polarity in a battery circuit.

We see from this that it is extremely important to make sure that the generator is properly polarized before operating. All that is necessary to reverse the polarity of the generator is to momentarily pass a current through the field windings in the opposite direction. As this can happen very easily when a generator is being serviced or disconnected from the circuit for any reason, it is very important to properly polarize the generator before it is placed in service.

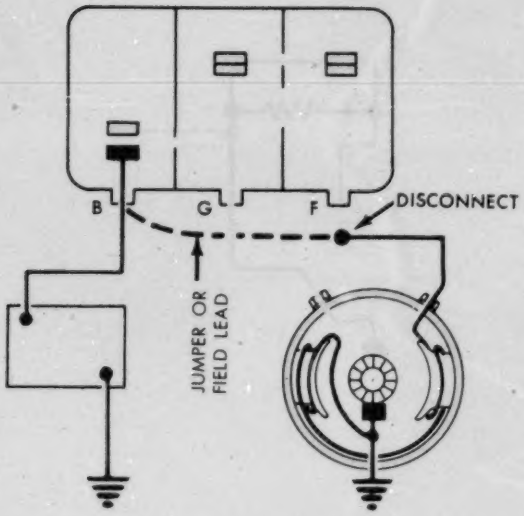
## POLARIZING GENERATORS

The procedure for correcting the polarity of the generator depends upon the generator regulator wiring circuits, that is, whether the generator field is grounded in the generator or whether it is grounded in the regulator.




Illust. 90—Polarizing "A" circuit generator.

If the generator field is grounded in the regulator, as shown in Illust. 90, it is termed an "A" circuit generator. Generators of this type can be polarized properly by connecting a jumper lead momentarily between the "bat" terminal on the regulator and the "Gen" terminal. Only a touch of this jumper lead is required and a flash will be noted when the jumper lead is removed. This jumper lead should not be left on any length of time because a high discharge current through the armature will tend to cause burning of commutator segments and brushes.




Illust. 91—Polarizing a "B" circuit generator.

If the generator has the field circuit grounded inside the generator, it is termed a "B" circuit generator and the procedure for polarizing it is slightly different.

Illust. 91 shows the circuit diagram of a "B" circuit generator. You will notice that one end of the field coil is grounded at the main brush in the generator. In order to polarize this generator, it is necessary to remove the field lead from the regulator "F" terminal and connect a jumper between this lead and the "bat" terminal of the regulator.

It is important to remove the field lead from the regulator in this case, because failure to do so will cause a high current to flow through the regulator points and the armature to ground, burning the points in the regulator.

The "B" circuit generator, however, is not used on any tractor or farm equipment applications at the present time. The "A" circuit type is the only one used.

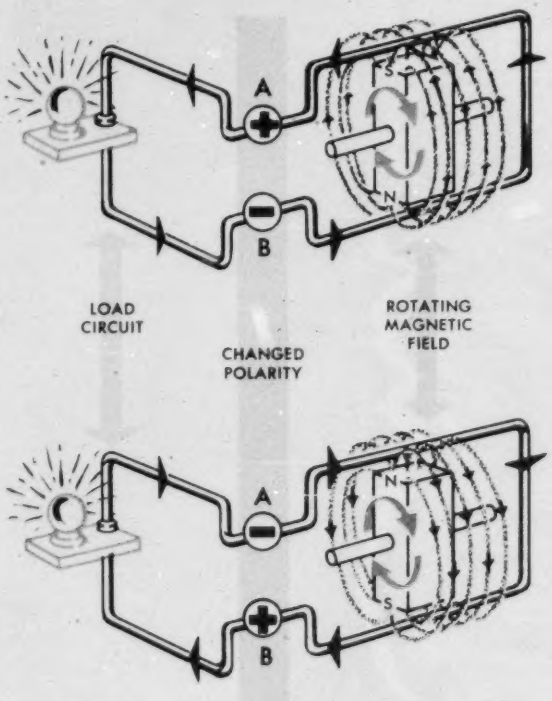
## THE A.C. GENERATING CIRCUIT

In the previous section of this manual we have seen how batteries can be charged and the voltage and current flow can be regulated from a direct current (DC) generator.

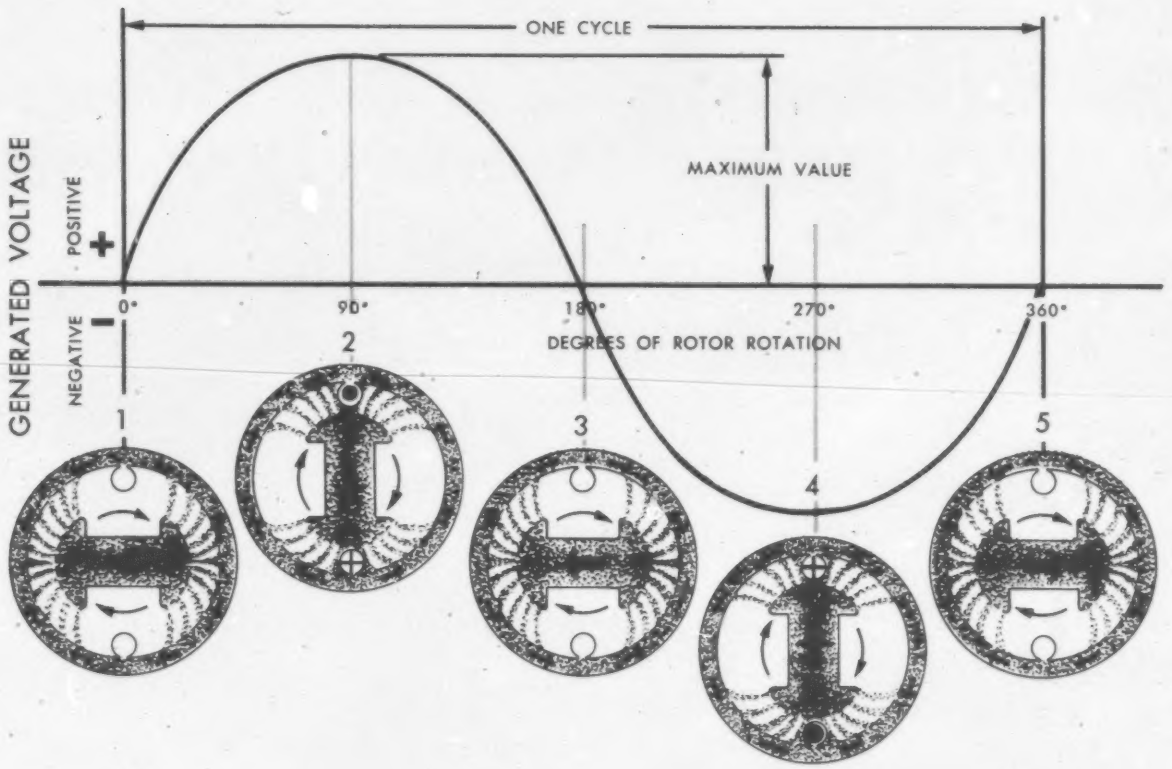
Alternating current (AC) generators are also used for supplying electrical energy for power equipment. Alternating current differs, as the name implies, from direct current in that the direction of flow completely reverses itself at regular intervals. The "frequency" of the reversals will depend on the speed of the generator and is given in cycles per second. But since alternating current cannot be used to recharge a storage battery, it is necessary to change or "rectify" it to direct current. A complete alternating current circuit for automotive equipment then will consist of the generator, rectifier, ignition switch, field relay and voltage regulator, the storage battery and the necessary connecting conductors.

### ALTERNATING CURRENT GENERATOR

The alternating current generator, like the direct current generator, produces an electrical potential or voltage in a conductor which cuts or passes through magnetic lines of force. As shown in Illust. 92, the (AC) generator differs from the (DC) generator in that the (AC) conductor is stationary and the magnet revolves while the (DC) conductor revolves and the magnet is stationary.




Illust. 92



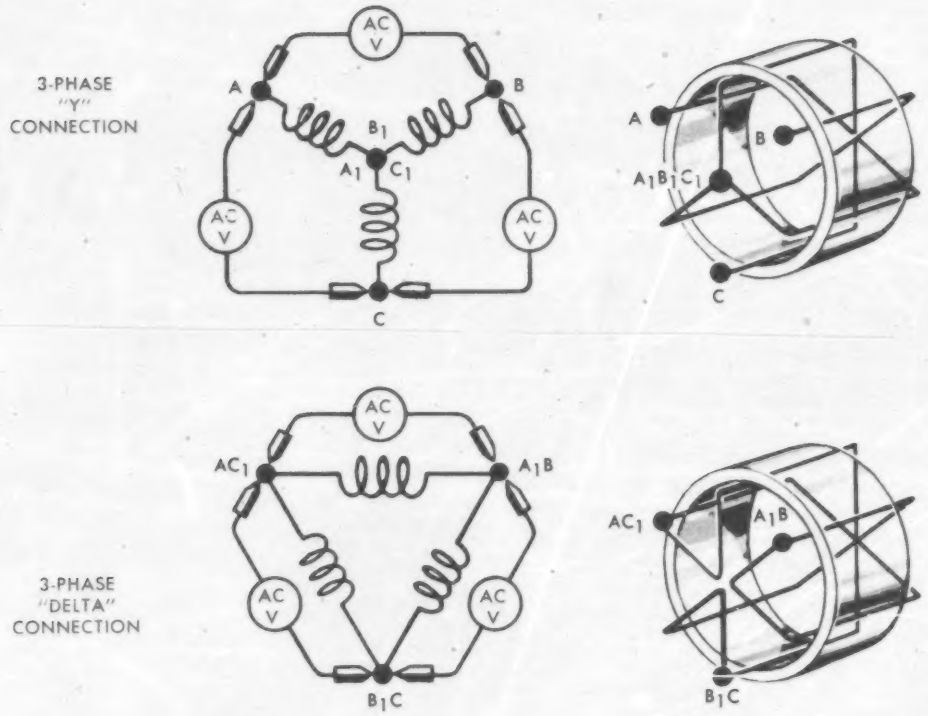

Illust. 93—Graph of potential.

When the magnet is revolved on a shaft between the sides of a loop, the magnetic lines of force are cut as they move past the conductor and a potential is created in the conductor which forces current through the load in a direction indicated by the right hand rule. As the magnet continues to rotate, the magnetic lines of force will again be cut by the conductor, but the poles of the magnet have now been reversed. The lines of force are also reversed and the right hand rule indicates the current will flow in the opposite direction. After a second one-half revolution, the magnet will be back at the starting point and the current in the conductor will flow in the original direction. Hence, we have two reversals of potential for each revolution of the magnet.

This alternating potential is graphically shown in Illust. 93. It will be noted that the conductor is attached to the inside of the stationary iron frame (now called the stator) and that the poles of the magnet (now called the rotor) are enlarged at each end to provide a wider area for magnetic lines of force.

As seen in the illustration, there is no potential in the conductor when no lines of force are being cut (position 1) but as the rotor rotates in a clockwise direction, the magnetic fields cross the conductor in gradually increased concentration until maximum potential is created in one direction (position 2). Then, as rotation continues, the potential gradually lessens as the fields leave the conductor until at position 3 the fields have passed and no potential is created. Further rotation of the rotor brings the opposite fields of the rotor to the conductor and potential is created in equal amount, but in the opposite direction.

We have learned that the potential or voltage created will be in direct proportion to the number of conductors, the strength of the magnetic field and the speed of the conductors through the field. It follows then that any desired voltage may be obtained by increasing

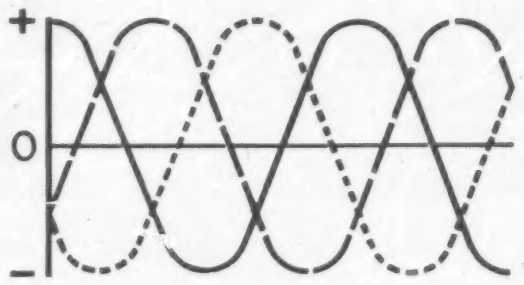



Illust. 94—Y and Delta windings.

or decreasing the number of loops wound into a stator, but it should be noted that the "frequency" or cycles per second is controlled entirely by the revolutions per minute of the rotor.

In practical use, the output and efficiency of (AC) generators is increased by winding three distinct sections into the stator. This may be done in either of two ways, as shown in Illust. 94. Note that in either case there are three windings connected to three terminals. As a magnetic field is rotated through these coils equal potentials will be created in each coil but at different phases of the rotor revolution. Hence, there will be three phases of the current in each direction for each revolution of the rotor. This is graphically shown in Illust. 95.

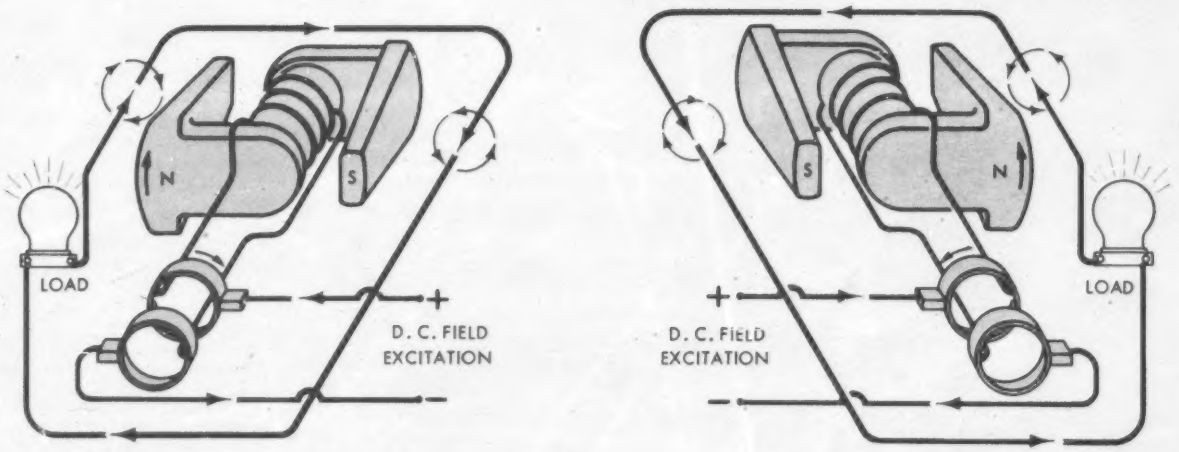
As with the (DC) generator, the output of the (AC) generator is controlled by the strength of the magnetic field which is now in the rotor. This field is created by a winding wound concentric with the rotor shaft, which




Illust. 95

is energized or "excited" by an outside source of (DC) current and is known as an "excitor." Since a circuit must be completed to this excitor while the rotor is revolving, connection must be made through the use of brushes and slip rings, as shown in Illust. 96.

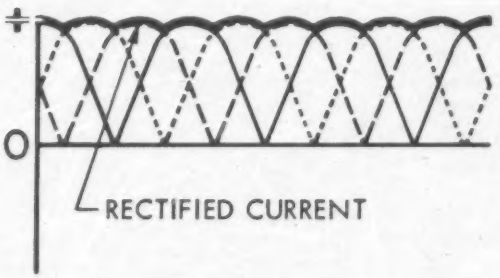
In actual use, the rotor will be made up of either two or six electro-magnets and will provide either four or twelve poles of alternate polarity. Consequently, the number of cycles




Illust. 96

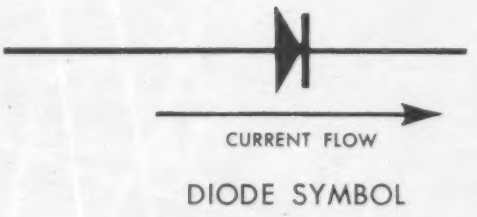
per revolution of the rotor will increase to two or six.

In the battery section of this manual, it was learned that direct current must be used to recharge a storage battery. Therefore, alternating current must be "rectified" into a current which will be suitable for battery recharging. This is done by eliminating all the voltage potential, on either the positive or negative side of the neutral line, and using only that potential voltage on the other side of the neutral line. The resultant rectified current is graphically shown in Illust. 97.




Illust. 97—Rectified current

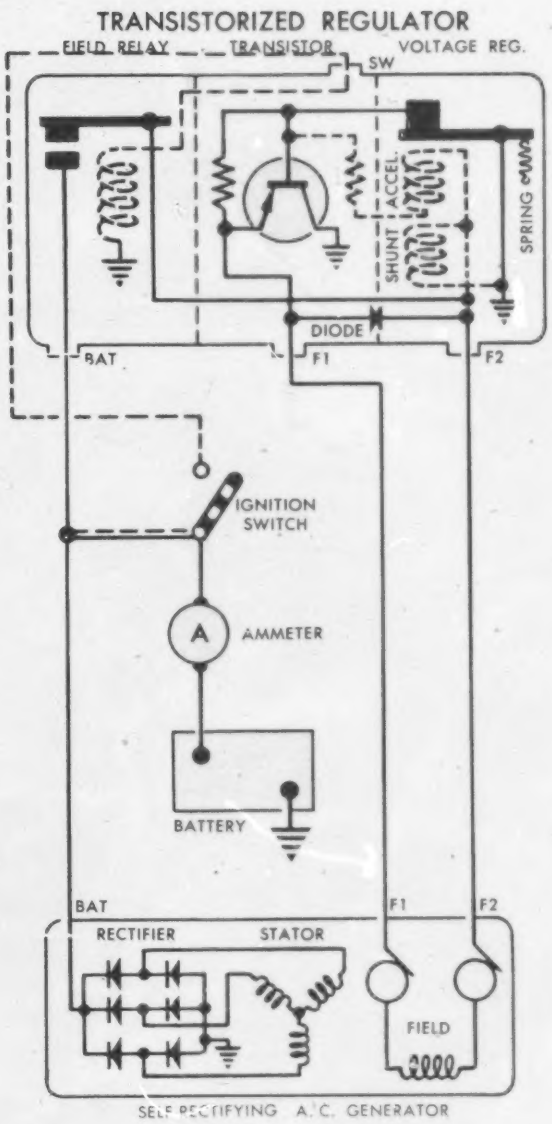
Rectification of (AC) current can be accomplished in a number of ways, but the modern and most efficient method is by the use of diodes. The chemical composition of a diode is such that it will allow current to pass through itself in only one direction. Consequently, when placed in a circuit which is energized by alternating current, it acts much like a check valve in a water or hydraulic system and allows the current to flow in one direction only. The diode is pictured in circuit diagrams as shown in Illust. 98.




DIODE SYMBOL

Illust. 98—Diode symbol.

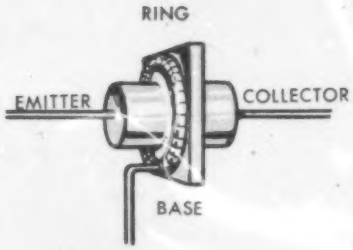
In the (AC) generator, a diode is placed in each of the three phases of the generator circuit, positive diodes being used with a negative grounded battery. From the three diodes, the three phases are joined together, and to the "BAT" terminal on the generator. Thus, (DC) current which flows in only one direction, flows to the battery and/or to the lights, etc. connected to the system. However, provision must be made for the completion of the circuits to each phase by connection to ground. This is done by placing a negative diode (if negative battery terminal is grounded)) between each phase from the generator and ground. The connections through the six diodes are shown in the generator portion of the diagram in Illust. 99.




Illust. 99—Schematic diagram.

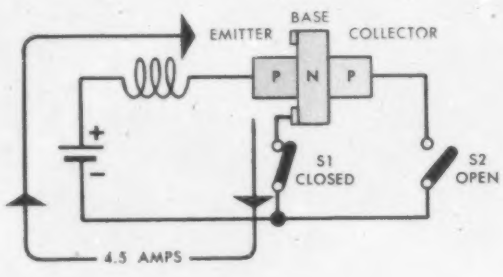
## TRANSISTORIZED REGULATORS

The four terminal transistorized regulator, used with the (AC) generator when an ammeter is used, accomplishes the same purpose as the (DC) regulators, but in a different way. There is no cutout relay as the diodes prevent current flow back through the generator from the battery when the generator is idle or operating at slow speeds. The cutout relay is replaced by a field relay and the voltage regulator operates through a transistor.



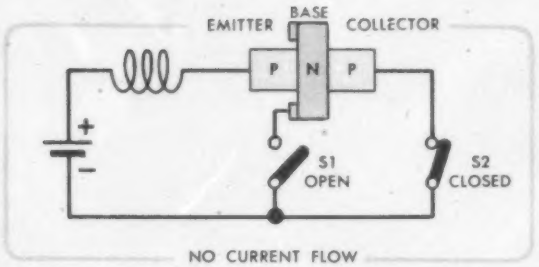

Illust. 100—Transistor.

To understand the operation of the voltag regulator, the characteristics of the transistor must be known. The diode, which we have learned permits the flow of current in only one direction, is made of a "P" (positive) material and a "N" (negative) material. The transistor is made up of two sections of "P" material and one section of "N" material or "base" between. The two "P" sections are known as the "emitter" and the "collector" as shown in Illust. 100.

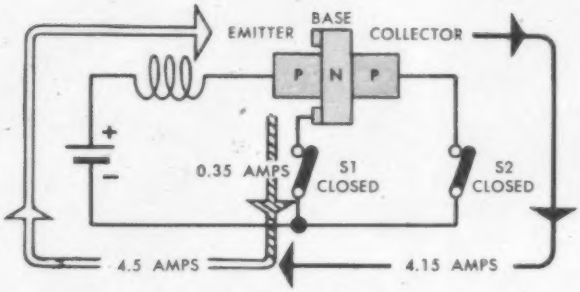



Illust. 101

When connected in a (DC) circuit, current will flow freely through the emitter and base sections, as shown in Illust. 101. However, it will be seen in Illust. 102 that no current will flow through the emitter and collector sections when the base section is not connected. But when the base section is connected, then a very small part of the current will flow through the base and a large part will flow through the collector, as shown in Illust. 103. Thus, it will be seen that practically a full flow of current through the emitter and collector may be controlled by controlling a much smaller current flow through the emitter and base sections.




Illust. 102




Illust. 103

Referring again to Illust. 99 we see that the regulator has two units, a field relay and a voltage control.

The field relay armature is connected in series, through the transistor, with the field coils in the generator rotor. When the ignition key is turned "on," the magnetic coil in the relay is energized, the relay points are closed and the field circuit is completed through the regulator points and also through both the transistor emitter-base and emitter-collector circuits. At the same time, the shunt and accelerator windings on the voltage regulator unit are energized, but the voltage at that time is not sufficient to open the regulator points.

As the generator speed is increased, the voltage from the generator will increase and current will flow through the battery, lights, etc. As the speed further increases, the voltage and current flow through the battery will become excessive and must be controlled by the regulator. Note that the voltage is impressed upon the shunt and accelerator winding in the regulator. When the voltage has increased to the desired potential, the combined pull of the two windings will open the regulator contact points and the emitter-base circuit to ground. The opening of the emitter-base circuit then opens the emitter-collector circuit and the field circuit. The generator voltage then immediately decreases, the magnetic pull of the two coils is decreased and the points are closed by the adjustable spring tension. This action completes the emitter-base circuit which allows the field current to pass through the emitter-collector circuit and the field circuit to ground. This action occurs many times per second and thereby regulates and controls the generator output to the desired voltage.

It should be noted that the current flow through the regulator contact points is only that small amount which flows through the emitter-base circuit. The total amount of field current which flows through the emitter-collector would cause burning of the contact points but the very small flow of emitter-base current can be interrupted many times per second without burning or pitting the points.

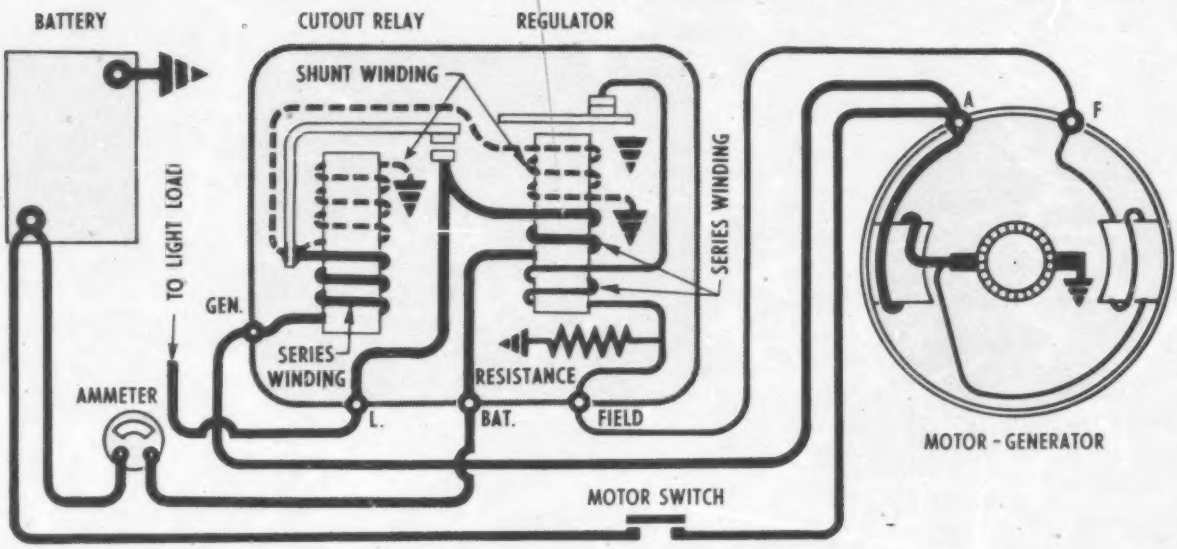
The accelerator winding in the regulator coil carries no current when the points are open. The loss of this magnetic pull, plus the reduced pull of the shunt winding, permits the spring to reclose the points in a very short period of time. Once closed, the magnetic pull is restored immediately and the points reopen. This winding, then, speeds up the frequency of vibration and therefore is called the "accelerator" winding.

Note that there is a resistor connected across the emitter and base of the transistor. This resistance acts to prevent emitter-collector "leakage" when the regulator points are open under high temperature conditions.

The resistance in series with the accelerating winding and the contact points is a design feature permitting the use of a required size wire for the winding.

The diode is connected directly across the field coil leads. Its purpose is to prevent an excessive build-up of voltage in the field coils caused by the interruption of the field current. This high voltage would cause a failure of the transistor, and the diode provides an alternate circuit where the current can flow without inducing the high voltage in the windings.

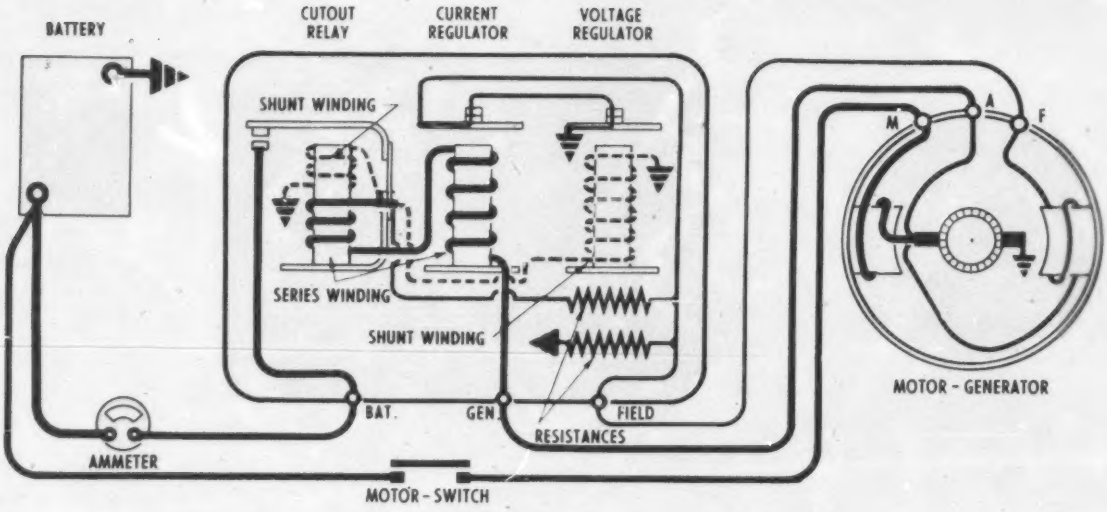
# Combination Motor and Generator




Illust. 104—Wiring diagram of motor-generator with 2 unit regulator.

This unit combines a cranking motor and a generator into one unit. When the cranking motor switch is closed, the unit operates as a cranking motor for starting the engine. When the engine starts and the motor switch is opened, the unit operates as a generator. Since this is a combination unit, it is engaged with the engine at all times.

You will note in Illust. 104 that the generator contains one heavy series winding (shown in red) and a shunt winding (shown in blue). When the unit operates as a motor, battery current flows through the heavy series winding, and also the shunt which helps in developing torque. When the unit operates as a generator, the shunt field is the main field and the series field acts as a bucking field to limit generator output at high speeds.




Illust. 105—Motor-generator with three unit regulator.

The motor-generator may also be used with a three unit regulator as shown in Illust. 105.

You will note that the wiring in the generator is slightly different when a three unit regulator is used, in that an additional lead is brought out from the series winding for the motor circuit. When this unit operates as a generator, the shunt winding is the only winding being used. The series winding is bypassed. With this arrangement, a greater output at high and low speed can be obtained because the series field is not acting as a bucking field.

The motor-generator is used on small motors where cranking loads are not great and electrical loads are not excessive. One advantage of this unit for small motors is that due to the series and shunt field windings, the free motor speed will not be excessive. This permits connecting the motor by means of a belt without danger of the motor overspeeding if the belt should break or come off during cranking. Regular series wound cranking motors are always connected directly to the engine to prevent excessive speeds which would occur if allowed to run free.